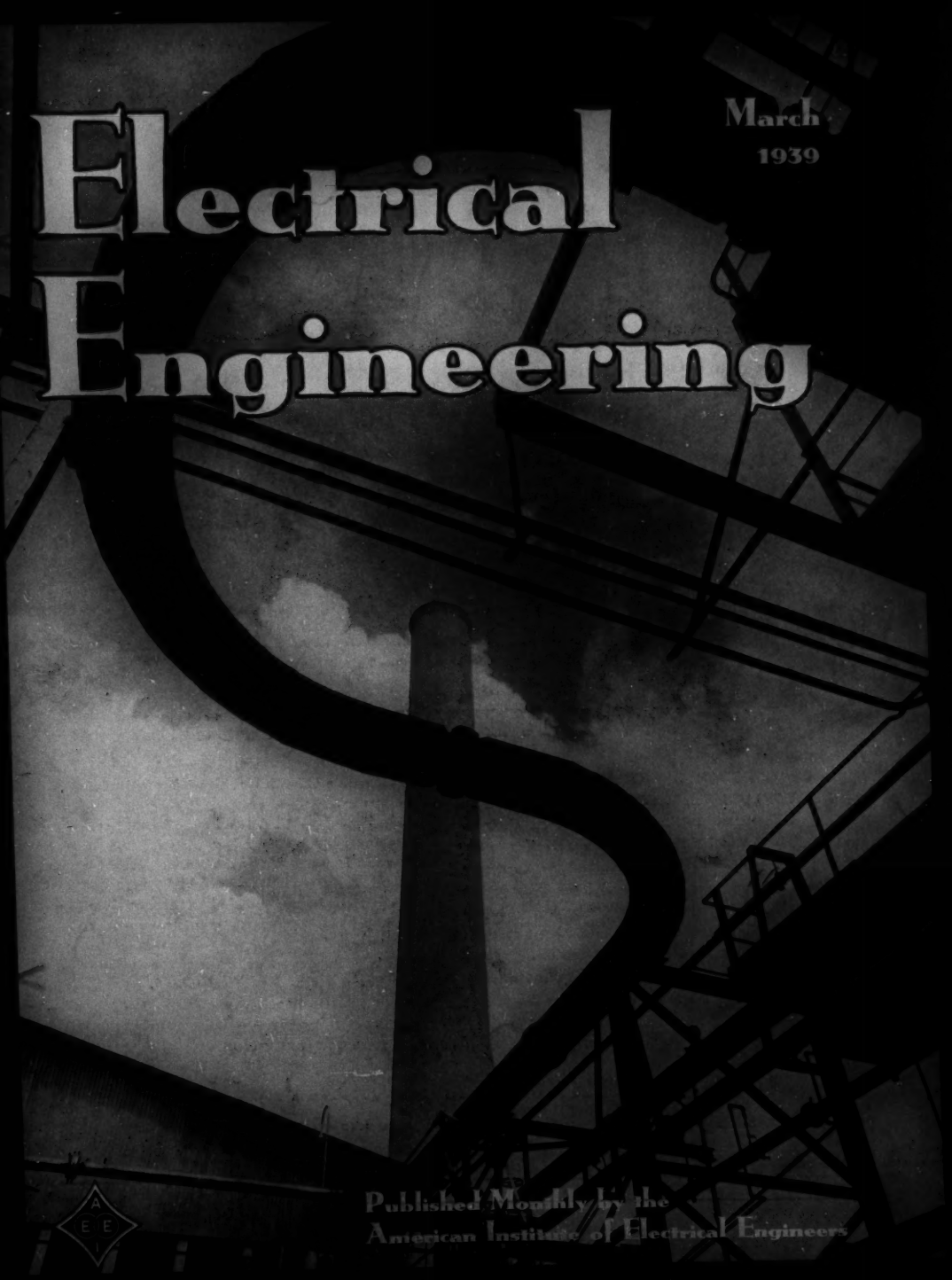
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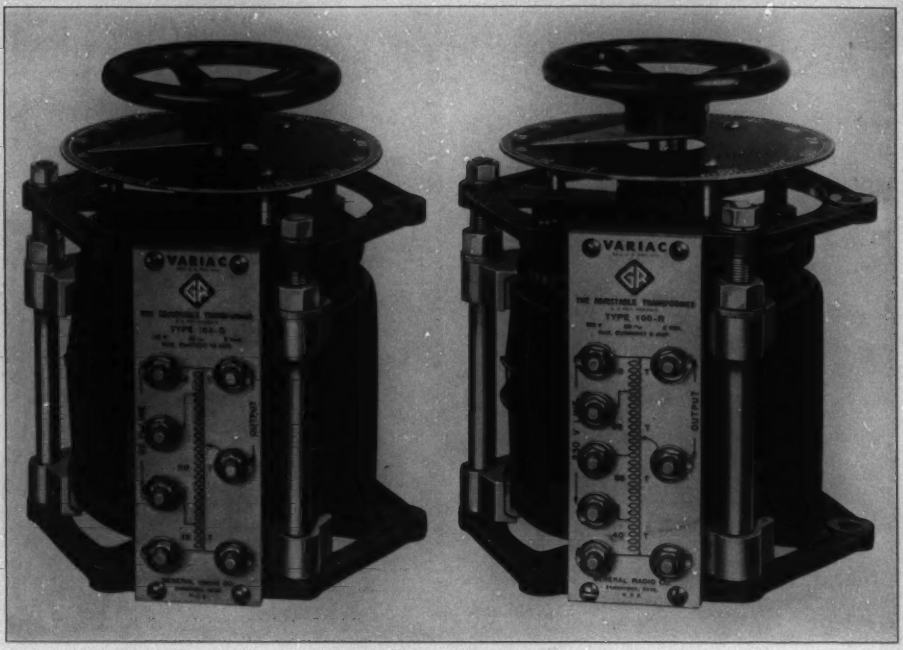


Type 100-Q and Type 100-R

TWO NEW VARIACS

• GENERAL RADIO announces two new VARIACS developed to fill a definite field where "above-line" voltages are desired. These VARIACS in general are similar to the 2 kva Type 100 except that bigger cores are used, improved terminal plates include the wiring diagrams, pigtails are provided to reduce heating of brushes and longer brush springs maintain uniform tension.

The Type 100-Q VARIAC supplies continuously adjustable output voltages from 0 to *135* volts on a 115-volt circuit with a rating of 18 amperes.

The Type 100-R VARIAC supplies output voltages continuously adjustable from 0 to *270* volts from a 230-volt line, with rated current of 9 amperes.

Both models are provided with reversible calibrated dials and with terminals so that either a maximum output voltage equal to the line voltage or equal to the above higher-than-line voltages may be obtained.

Both models are priced at $40.00 each.

• *Write for Bulletin 387 for Complete Information*

GENERAL RADIO COMPANY

Cambridge, Massachusetts

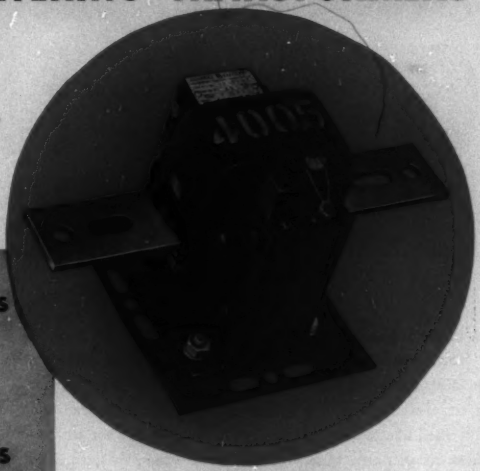
BRANCHES: NEW YORK AND LOS ANGELES

MANUFACTURERS of PRECISION ELECTRICAL LABORATORY APPARATUS

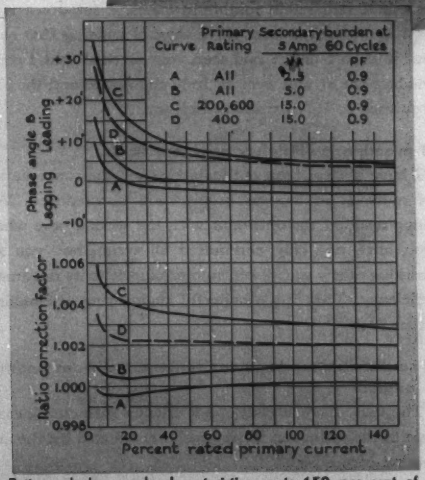
THESE NEW G-E METERING TRANSFORMERS

OFFER ADVANTAGES OF WIDE RANGE, ACCURACY, SIMPLIFIED STOCKING

Type JL-1 600 Volts
Three Ratings
200/5, 400/5,
and 600/5 Amperes



SMALL SIZE
HANDY SECONDARY TERMINALS
SILVER-PLATED CONTACT SURFACES



Ratio and phase-angle characteristics up to 150 per cent of primary-current rating.
Notice the outstanding accuracy of Type JL-1—particularly at the lower values of primary current. Such accuracy is obtained by means of the Wilson Compensation scheme—an exclusive G-E feature

WITH General Electric's new Type JL-1, you get a line of metering transformers designed to operate continuously at 150 per cent of their rated current—200, 400, and 600 amperes.

You get current transformers that provide maximum accuracy from 5 per cent to 150 per cent rated current. You benefit from reduced transformer stock. You profit from the ability of the JL-1 to serve a large variety of loads with few replacements.

This new, small-sized G-E transformer offers many advantages. Primary terminals are of the two-bolt-hole type, silver-plated to assure clean, noncorrodible contact surfaces. Solderless, clamp-type secondary terminals are provided, and a handy potential connector, on one terminal pad, eliminates the need for cutting into heavy cable. A detachable mounting plate makes it possible to minimize installation space—permits mounting on flat surfaces or pipe.

For a complete description of the new Type JL-1, call the nearest G-E office or write for Bulletin GEA-3095. General Electric Company, Schenectady, N. Y.

GENERAL ELECTRIC

What Men Like You

G-E SPIRAKORE

A New England utility executive states:
"Your wound-core construction is the biggest advance in distribution-transformer design that I have seen since I first started in the utility game twenty years ago. I would like to see this design in the larger sizes just as soon as you can possibly furnish it—say, in sizes 5 to 25 kva—and why stop there?"

A Southern utility engineer, in charge of maintenance and repair, states:
"It looks as if my job is going to be easier from now on. That wound-core transformer is so simple that there does not seem to be anything on it to go wrong. I do a lot of transformer designing in my line of work, and I can usually see things in a manufacturer's design that can be made better if done my way; but this is one time when you fellows have made a transformer which I can't think of any way to improve upon."

An Illinois utility purchasing agent states:
"This new wound-core design is the biggest contribution to the extension of rural electrification that has been made since our program for installing rural lines started. The lower cost has made possible the addition of several transformers in at least one locality where our budget figures indicated it would not be economical to supply service without the lower investment."

A New York State operating engineer said:
"I could stand here and watch that machine all day! It's fascinating! Every transformer leaving that machine is exactly like the last one. It is the last word in uniformity."

After seeing the core-winding operation, one customer remarked:
"I have seen the wound-core sample transformer your specialist had, and it looked so neat and compact I wondered why you had not built that design years before. The specialist told me that it was because no one had figured out a way previously to assemble the core and still retain minimum losses. I sat down later and figured out at least three ways of winding that core, but it wasn't until I had seen your method that I could see how the strains were entirely eliminated and the core iron used to its maximum efficiency."

A prominent efficiency engineer said:
"I have always been enthusiastic over the conservation of material as long as quality was not reduced. You have reached the optimum with the wound core where you have not only eliminated all scrap, but you are working every square centimeter of iron to its maximum efficiency. That is a wonderful engineering accomplishment."

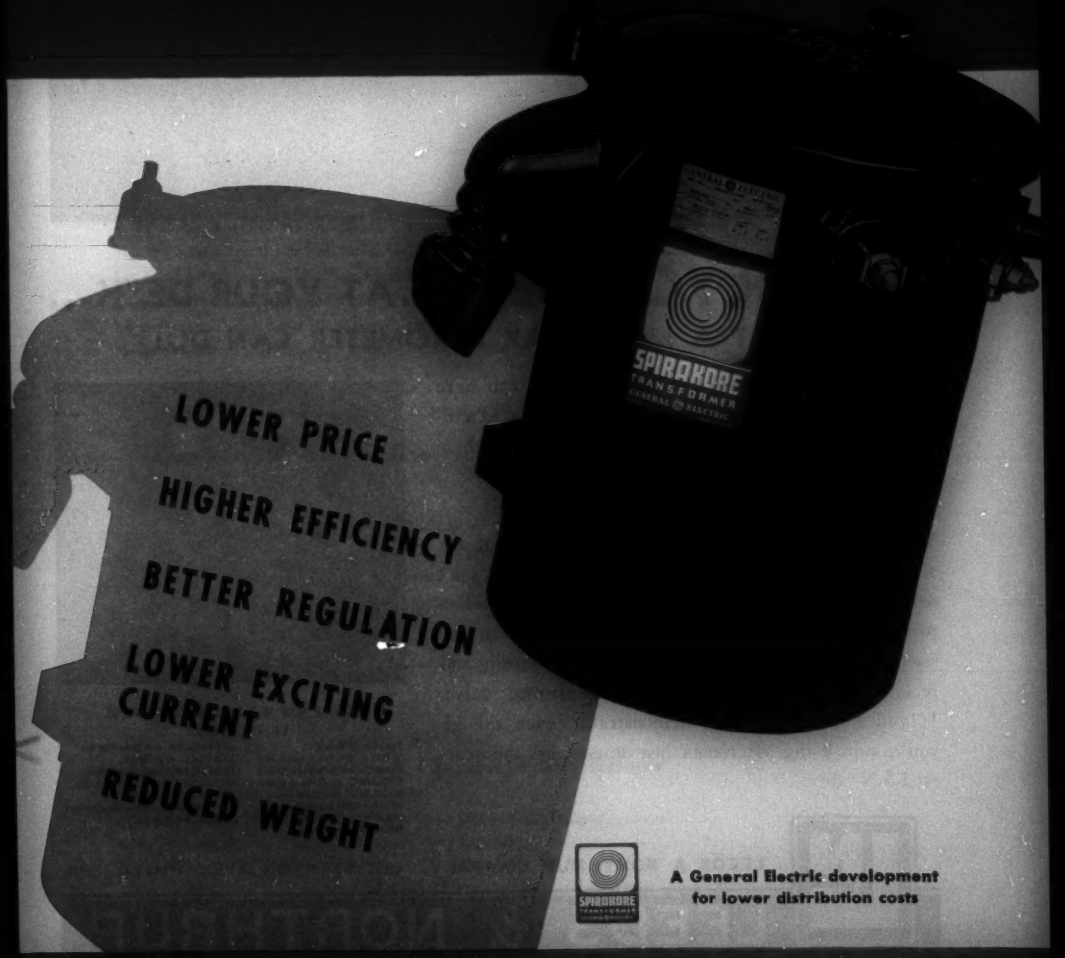
One distribution engineer commented from another angle:
"The G.E. have already made friends with our linemen due to the reduction in physical size effected by the new wound-core design."

For additional facts about the SPIRAKORE transformer, ask your G-E representative for brochure GES-2038, which tells the story of the development of the wound-core design. For complete descriptive data, ask for Bulletin GEA-3085. General Electric, Schenectady, N. Y.

GENERAL

are Saying About the

TRANSFORMER



ELECTRIC

See FOR YOURSELF...AT YOUR DESK...

WHAT A MICROMAX PYROMETER CAN DO!

Here's a handy demonstrator in which you can have the much-discussed micro-balancing unit of a Micromax Pyrometer brought right up on your desk—where you can see what it does and decide what it offers . . . even better than by watching the instrument itself.

You can set it to simulate a temperature change of any size—yet even when the change is so tiny that you can't see the galvanometer move, you can still see the motion produced in the balancing mechanism, and you can also see how that motion would be carried to indicating and recording mechanisms and to the controlled valve. If you haven't seen this demonstrator, even though you're now using Micromax instruments, ask the nearest L&N office.

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Electrical Engineering

Registered U. S. Patent Office

for March 1939—

The Cover: A view in an eastern Texas oil refinery; some phases of the oil industry will be discussed at the AIEE South West District meeting in Houston, Tex., April 17–19, 1939 Photo by Robert Yarnall Richie

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¶ Correspondence is invited on all controversial matters.

High Lights

Hurricane Experiences. On September 21, 1938, the first major hurricane in that territory for more than a century swept across Long Island, N. Y., and parts of the New England states, leaving a trail of devastation in its path. Some 500 people were killed, and 2,000 injured; property damage is said to have been the greatest that has been caused by any disaster of historic times in America; public utilities, which play so vital a role in modern life, were incapacitated. With a view to determining any engineering conclusions that might be drawn from the experiences following the hurricane, one general session of the recent AIEE winter convention was devoted entirely to a discussion of the general damage caused by the storm (*pages 99–101*) and of its effects on the railroads (*pages 102–04*) the power utilities (*pages 105–10*) and the telephone systems (*pages 111–12*).

Rectifiers. Research since the introduction of the copper-oxide type of rectifier in 1927 has broadened the possibilities for its application beyond its uses for battery charging and as a valve in control circuits. By spraying a conducting coating on the copper oxide, rectifiers may be constructed from plates considerably larger than the usual disks, and the ratings increased to values suitable for electrochemical applications (*Transactions pages 103–06*).

Interconnection Control. Automatic control has been applied to an interconnection between power systems to enable the maximum transfer of energy without separation of the systems. By means of carrier current a continuous indication of the phase-angle difference between the systems is obtained, and the output of generating units at the control station regulated automatically to maintain the angle within desired limits (*Transactions pages 83–93*).

Colorado River Aqueduct. Boulder Dam power plant ultimately will supply 300,000 kw to operate pumps for an aqueduct bringing 1,500 second feet of water from the Colorado River to southern California. A description of the 220-million-dollar project, including the electrical equipment and transmission system for the five pumping stations, is given in this issue (*Transactions pages 112–23*).

Power Limits. Static power limits of synchronous machines may be determined accurately by an analysis in which resistance, shunt loads, salient poles, and saturation are considered, and which by application to operating systems may indicate changes in load dispatching that would result in higher power limits and increased reliability (*Transactions pages 93–102*).

Image Transmission. Line images such as drawings, diagrams, and animated cartoons may be transmitted by a system which requires a frequency band not exceeding 10,000 cycles in width and hence could be accomodated on telephone lines with suitable modification. Reproduction is by means of a cathode-ray tube; simplification is obtained by omitting the transmission of blank areas (*Transactions pages 124–7*).

District Meetings. A program of technical sessions on varied subjects and entertainment features has been announced for the AIEE South West District meeting at Houston, Tex., April 17–19, 1939 (*pages 129–30*). Plans are nearing completion for the North Eastern District meeting to be held at Springfield, Mass., May 3–5, 1939 (*pages 130–1*).

Ferroresonant Circuits. Application of the principle of similitude to the generalization of ferroresonant circuits offers a simple solution for the critical conditions, and enables the critical stable conditions of any reactor to be predetermined from those of a known reactor using the same grade of iron (*Transactions pages 127–30*).

Nominations for AIEE Offices. The Institute's national nominating committee met during winter-convention week to designate nominees for election to Institute offices for the year 1939–40 (*pages 128–9*). Biographical sketches of the nominees are included in the "Personals" section of this issue (*pages 134–6*).

Winter Convention. Registered attendance at the 1939 AIEE winter convention was the highest since 1924. The program included 17 technical sessions, 2 general sessions, 5 technical conferences, presentation of both the Edison and John Fritz medals, and the usual entertainment events and inspection trips (*pages 123–8*).

Postgraduate Courses. A study of engineering education as a whole seems to be needed to point to the best way to give graduate training and to fix the graduate curricula. The necessity and usefulness of ordinary present-day graduate courses are seriously challenged (*pages 118–22*).

Petersen Coils. Excessive currents may flow in Petersen coils on systems in which the capacitances to ground of the transmission-line conductors are unbalanced. These undesirable circulating currents may be reduced by rearrangement of the circuits (*Transactions pages 107–12*).

Social Participation. Engineers wishing to participate in matters pertaining to social philosophy might do so through groups organized for social, economic, or political purposes to better advantage than through professional technical societies (*pages 113–14*).

John Fritz Medalist. At the recent AIEE winter convention the 1939 John Fritz Gold Medal was presented to a prominent Institute member whose biography indicates his eminent qualifications for this honor (*pages 115–17*).

Bylaw Amendment. Among actions taken at a recent meeting of the AIEE board of directors was the amendment of a section of the bylaws pertaining to technical papers (*pages 131–2*).

Coming Soon. Among special articles and technical papers undergoing preparation for early publication are: an article outlining the qualities of a profession by Vannevar Bush (F'24); an article on the definition of engineering experience by C. F. Scott (HM'29); contributed discussions of the article "Graduate Training for Engineers" which appears in this issue; an article describing gearmotors and some of their applications; a paper on the reconditioning of insulating oils by activated alumina by J. E. Housley (A'19); a paper on generator damper windings at Wilson Dam by R. B. George (M'27) and B. B. Bessesen (M'27); and a symposium on operation of the Boulder Dam transmission line, consisting of papers on the general operation of the line by W. S. Peterson (M'29), insulation and lightning protection by Bradley Cozzens (A'28), corona experience by these two authors jointly, carrier-current equipment by J. D. Laughlin (A'36), and relay protection by L. L. Draper (A'29).

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Experiences From the New England Hurricane

With a wind velocity as high as 186 miles per hour, and traveling forward as fast as 65 miles per hour, the hurricane that devastated parts of Long Island and New England on September 21, 1938, was the first storm of its character to afflict this territory in more than a century. The storm originated at least ten days prior to that time in the Caribbean Sea and was expected to strike the city of Miami, Fla., but turned north instead; later, it veered unexpectedly to the west as it progressed northward, gaining in intensity and momentum, and with unpredictable fury swept across a territory where a hurricane of any sort is a rarity. The story of the terrible destruction and loss of life left in its wake already has been told, as has been the story of the tremendous damage to the various public-utility systems and the added suffering resulting from the temporary loss of these services. With a view to determining what if any engineering conclusions might be drawn from the experiences following the hurricane that might be of value in the future, one of the two general sessions of the AIEE 1939 winter convention was devoted to a presentation and discussion of six addresses on this subject. The following six articles embrace the essential substance of those six addresses.

I—General Review of the Storm and Its Effects

By WALTER WESSELIUS

THE Red Cross operates in many, many disasters—on an average of a hundred per year—and this last year was no exception. In fact, during the past year, domestically we handled through the national organization and its chapters 129 disasters divided between floods, cloudbursts, epidemics, tornadoes, and miscellaneous other types of disasters.

Some disasters are predictable and others are not. Among those on which we have and can get advance information are, of course, floods and hurricanes. Over the past many years, the Red Cross has developed very intimate functional and co-operative relations with many departments of the government, and our relations with the Weather Bureau have been exceedingly close.

In the instance of the storm which finally hit New England on September 21, 1938, we had been apprized by the Weather Bureau in Washington at least ten days previously that a tropical disturbance was in the making way out in the Caribbean and that it seemed to assume the proportions of a hurricane. From that time on, we obtained from the Weather Bureau at three-hour intervals specific information as to that storm, the degree of intensity as the indications pointed, the direction, and other factors which would prove helpful to us in formulating our plans. For a period of several days, we marked our map, with the pins set at regular intervals; the storm was traveling straight as a die and, if carried on, would have finally hit the city of Miami, Fla. It seemed then certain that it would, although the Weather Bureau cannot, of course, and will not, advisedly, state that a storm will hit any point until it is reasonably close. In the meantime, the machinery of the Red Cross was put into operation. Every chapter in the state of Florida was advised of the storm coming and that further information would be given as it became available.

We set in operation certain mechanics of insuring communications by radio if and when communication was disrupted, as it usually is in a hurricane. We tightened our lines with respect to the evacuation of known hazardous areas, particularly the Lake Okeechobee area, through our relations with the Florida East Coast, the Atlantic Coast Line, and other railroads, so that that area could be immediately evacuated. We had our personnel on the trains actually on the way. We were ready to co-operate with the local leadership, those who comprised our voluntary chapter organizations for dealing with disastrous situations. Our staff had reached Jacksonville, but during the night word had been received in Washington that the storm had veered directly north, slightly to the west. We were able to recall our people from Jacksonville, and I was reasonably certain that the storm would not hit either Florida or the North Atlantic Coast.

As I recall the reports, it passed about 100 miles to the east of Cape Hatteras, N. C. It is axiomatic in observation of hurricanes that once a hurricane turns, it stays turned. Certainly a perusal of the record of hurricanes over the

Essential substance of an address presented at a general session of the AIEE winter convention, New York, N. Y., January 23–27, 1939.

WALTER WESSELIUS is assistant director of disaster relief, National Red Cross, Washington, D. C.

last 50 years supports that statement in a very general way.

Storm Departed From Usual Course

A hurricane, as is quite generally known, is a large tropical disturbance which may have a circumference or a diameter of 50 to 200 miles; ordinarily, it travels forward from 14 to 15 miles per hour, with its wind blowing counterclockwise from 75 to 200 miles an hour. At this rate, the 1938 storm would not have hit the New England coast for days, and, of course, there was no expectancy that it would ever hit there. In fact, we never think of hurricanes in connection with New England like we do with Florida, Cuba, Mexico, Louisiana, and other points in the South. But in this instance, history repeated itself. Records show that on September 23, 1815, a hurricane of similar size and intensity struck New England, and Providence, R. I., was inundated practically to the same degree as it was in the circumstances of last fall.

The storm seemed to have gained a tremendous momentum. I have seen no official statistics but I have heard reports that it traveled forward as fast as 55 to 65 miles per hour. We were watchful at national headquarters, awaiting reports. The first information that came to us was of a high wind at the Floyd Bennet Field. About an hour or two later, our field representative at Providence, mindful of the gale warnings, phoned that water was beginning to come into the city. In fact, it was already quite deep and a serious situation seemed to be developing. Directly after that, communications went out.

Within the next hour we had communication by way of amateur radio from Westerly, R. I., transmitting a message from our chapter chairman there: "For God's sake, send some help. Hundreds are drowning. Send boats. We need boats." We immediately transmitted that information to the Coast Guard station at New London, Conn., through the Washington office of the Coast Guard.

A little later reports came by way of short-wave amateur radio that the entire city of New London was burning. I left the same evening for New London and other members of our staff went forth to cover the various major points which were reported to us, and our communications went out to every one of our 194 chapters within the affected territory. Communication lines were down everywhere. It was very difficult to keep in communication, to ascertain exactly what happened; in fact, it was several days before we could report the degree of the loss of life and property and the relief measures that would be necessary.

The area affected by this storm comprised all of Long Island, Block Island, Fishers Island, and all of the State of Connecticut, all of Massachusetts, all of Rhode Island, and approximately half of New Hampshire and Vermont.

There is another situation with respect to this storm that was rather unique in our experience in that it was a disaster upon a disaster. There was a fire disaster at New London which, fortunately, was restricted to a relatively small part of the business district; but coincident with the hurricane, we were dealing with a flood situation along the Merrimac and Connecticut Rivers. These rivers were in flood in the Norwich area, in New London County, and at Hartford, Conn., and north of Hartford at Springfield and Chicopee, Mass.; the rivers in Central Massachusetts were all in flood at the same time. About 12,000 persons were then being cared for as refugees. The hurricane, of course, complicated the situation and made relief measures much more difficult, taxing the volunteer effort of our chapter people of the Red Cross who were dealing with this matter.

Some Damage Statistics

A few rough statistics concerning the damage done by the storm may be of interest. Approximately 500 persons were killed in New England, and about 2,000 injured; 2,000 year-round residences were destroyed, and about 45,000 homes damaged. I think it is a safe statement to say that nearly all homes in New England were affected to some degree in this hurricane from a few shingles to total destruction. Summer homes represented a major loss with about 7,000 totally destroyed, and about 8,000 damaged. Incidentally, it was in the summer homes where the great loss of life occurred. There was not the warning to New England which was available when the known facts of the storm were brought to our attention, where the storm first originated, namely, in Florida. Consequently, there were no preparatory measures, no warnings, nothing that could be done about it. The storm came on suddenly and did not follow the known characteristics of hurricanes.

About 2,500 barns were destroyed and about 6,000 damaged; other buildings, shacks, sheds, garages, outbuildings —7,500 destroyed, and an estimated 16,000 damaged. There was also great loss in animals—livestock on farms—475 work animals, 1,000 cattle, 200 hogs, and from 500,000 to 750,000 poultry.

Another phase of loss which was brought to our attention as a major consideration in our relief work later was that pertaining to the boat and fishing industry. New England has a great fishing business. Thousands of fishermen earn their whole livelihood in that manner. Following the storm, boats literally were scattered everywhere along the coast. It is estimated that 3,500 boats, from the small type to the largest, were either sunk, beached, ruined, or damaged, and an unlimited number of lobster pots and fishing paraphernalia necessary to the livelihood of these people.

Another serious loss is that pertaining to the terrific loss of trees. Everywhere these beautiful trees of 100 to 200 years of age were scattered right and left—pushed over like toothpicks.

Responsibilities of Red Cross

At this juncture it might be well to say a few words about a question on which there is often many questions—the respective responsibilities of government and of the Red Cross. The Red Cross has a fundamental responsibility imposed upon it by the charter given to it by the Congress of the United States many years ago to deal with the needs

of families who have suffered as a result of disaster. Quoting from the charter: "The Red Cross shall mitigate the sufferings caused by fire, flood, pestilence, and other diseases," and so forth, "and shall take steps for the prevention of same."

In disaster relief, government—city, county, state, and federal—has responsibilities of its own to carry out and these responsibilities correlate with those of the Red Cross in many ways. The Red Cross meets human needs, providing food, shelter, clothing, and medical aid, both at home and in shelters.

The correlated responsibility of government in disaster situations is the maintenance of law and order, the prevention of looting, the fundamental responsibility of government in the prevention of epidemic, communicable disease, control of communicable diseases, maintenance of public health, sanitation, and related there again is the question of caring for the dead which is imposed by law as a responsibility of the coroner.

Then there is the other side of the question. The Red Cross has the duty of rescuing people, bringing them to safe shelters and taking care of them until they can be returned to their home, if there is one, or until one has been prepared for them.

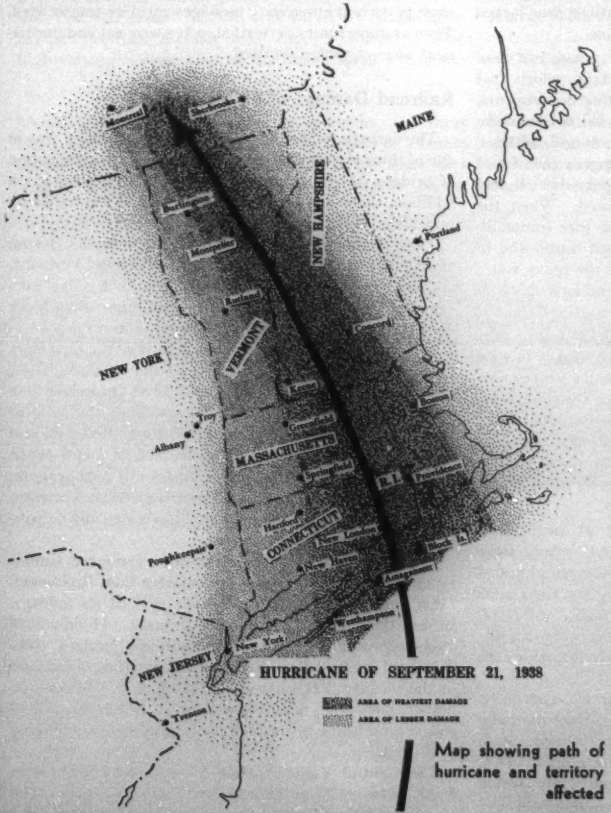
Now we can take care of people voluntarily but we do not have the power by law for forceful evacuation. There, again, we work hand in hand with government. If there is enforced evacuation, it is up to the public authorities to do it.

The Red Cross has the responsibility to provide family by family that which they need on a minimum basis which they could not provide themselves from their own resources, either potential or liquid. Thus we have the responsibility in the rehabilitation of families to provide those essentials necessary to bring those people back to a normal self-sustaining basis. That does not mean that we are supplying their losses.

We provide maintenance for those families until they can be cared for under their own resources, aiding them in the building of their homes, furnishing household goods, hospitalization where necessary, nursing care where necessary, farm supplies, livestock and equipment, and occupational assistance. On the other side, government with the 75 or 85 million dollars it made available, had the tremendous task of removal of trees from the highways and the byways, the repairing of bridges, sewer systems, water systems, and other public projects.

Of the 50 or more thousand families affected by this disaster, the Red Cross had applications from 18,935 families, of which 14,300 have been given assistance. We spent $800,000 on building and repair; $25,000 on medical care and nursing; $150,000 in occupational rehabilitation, chickens, repair of boats, and re-establishment of people in the one-man type of business; $200,000 in household goods.

Let it be said here that were it not for the marvelous ingenuity and self-help of the people of New England, we would never have completed this operation within a total sum of $1,700,000. It might easily have gone on to millions and millions. The self-help of these people in caring for themselves in so far as possible and in assuming credit where they had credit was one of the major factors not only for the speedy operation but for its minimum cost.



Map showing path of hurricane and territory affected

Although prepared to show severity of damage to telephone plant, this map is believed to indicate with reasonable accuracy the severity of damage to other utility systems and to other structures in general

Courtesy *Bell Telephone Quarterly*

II—Hurricane Experiences of the Railroads

By SIDNEY WITHINGTON
FELLOW AIEE

THE railroad appurtenances chiefly affected by the storms were: tracks, bridges, passenger and freight station buildings, signals, electric power generating, transmission, and distribution facilities, communication lines, and miscellaneous motors, such as shop, pump, float-bridge and track-switch motors, and drawbridge motors and control circuits. Various types of buildings, boats of all sizes, including a large lighthouse tender which required 17 days to remove, and other debris of all kinds deposited on the tracks, contributed relatively minor but still important problems in restoration of service. Busy passenger stations, such as that at Providence, R. I., and at New London, Conn., having been inundated, were without lights for a time. The railroad organizations thus lacked nothing of variety in re-establishing service.

Prior to the afternoon of September 21, there had been extremely heavy rainfall for several days, which had caused grave concern to railroad operating departments, and track patrols had been carefully conducted to insure against accidents to trains from washouts or landslides. There had indeed been considerable damage, some of it of a serious nature, before the hurricane appeared at all, and many trains were already being detoured. When the hurricane came it effectively interrupted wire communication over hundreds of miles of railroad route, and in view of the known hazards presented by the heavy rains, train service was arbitrarily cancelled, pending a check on the condition of the various routes.

In a number of instances, passenger trains in transit were blocked at outlying points, and it was necessary to take care of the passengers as far as possible until arrangements could be made to permit them to continue their journeys. The general blocking of highways and the absolute lack of communication facilities, both of the railroads and commercial communication companies, made this extremely difficult. It was not known, in some cases for many hours, just where trains might have been held up.

Interesting problems were presented at such intermediate terminals as New Haven, Conn., where large numbers of passengers collected in the absence of transportation facilities to permit them to continue their journeys, and were obliged to spend the night. After all available hotel accommodations had been assigned, the railroad placed Pullman cars and coaches for the use of the marooned passengers.

Restoration of passenger and freight traffic, each in its own way, was of vital concern. The large cities normally receive the major part of their food supply by rail each day, and if the flow is interrupted even for a brief period, distress results. For instance, with all routes into Boston from the west blocked, it was necessary to use such detour routes as were available, regardless of expense, and for a short time much of such perishable freight was detoured through Canada to Portland, Me., and thence to Boston.

The loss of the communication circuits, as well as of signals, was generally due to wrecking of the aerial circuits, partly on account of trees or other objects fouling the line, and partly on account of destruction from washouts. The most immediate problem in re-establishing service was the restoration of at least a bit of communication throughout the affected areas. This involved usually the laying along the ground of twisted pairs, and in some instances cable, through the damaged territory so that the most important emergency messages could be transmitted. Then as opportunity permitted, poles were set and permanent wires or cables installed.

Railroad Damage of Three Classes

The damage to the tracks themselves in general was in one of three classes: (1) washout of grade, (2) destruction of bridges, (3) landslides to the tracks from above; in addition, there was the frequent blocking of the tracks by miscellaneous foreign debris.

The railroads most seriously affected were the Boston and Maine, the Boston and Albany, the Central Vermont, and the New York, New Haven and Hartford. The Rutland and the Long Island and several other New York State railroads also were affected, but to a lesser degree.

The Boston and Maine Railroad was damaged especially between Gardner, Mass., and the Hoosac Tunnel, along the Millers River and the Deerfield River (both of which were considerably higher than they were in the flood of 1936) between Lowell, Mass., White River Junction, and Wells River, Vt., between Concord, N. H., and Wells River, and between Bellows Falls and South Ashburnham, Mass. There were 27 bridges seriously damaged or completely destroyed, 266 washouts, 22 landslides and 45 submerged locations of some length.

The Boston and Albany Railroad experienced similar types of damage on its main line between East Brookfield, Mass., and Albany, N. Y.—60 per cent of its mileage. Broken dams helped to swell the damage. Hundreds of washouts were reported. Six main-line bridges were destroyed (at East Brookfield and Huntington, Mass., and in the vicinity of Chatham, N. Y.) and five bridges on branch lines. At South Spencer and North Brookfield and several other points, freight houses were completely destroyed.

The Central Vermont Railroad suffered chiefly from floods between Norwich and New London, Conn. The terminal at New London was practically destroyed, and the railroad's large freight steamer "Vermont" was washed up against the yard tracks at New London and

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damaged. Two coast guard cutters were floated up to the door of the freight office building at New London and left there, and 25 other craft of all sizes were removed from the tracks between New London and Norwich. Considerable reconstruction was necessary at Palmer, Mass., Stafford, Lebanon, and Yantic, as well as at Norwich, Conn. The up-country damage on this road was far less than that caused by the floods of 1927 and 1936, though the 1938 situation was potentially as serious, if not more so. The credit for this has been assigned to the flood-control dams recently built in the White River tributaries at East Barre, Wrightsville, and Little River, Vt.

Several other railroads were affected in lesser degree than were the foregoing. The Rutland suffered 18 major washouts but, fortunately, no bridges were involved. The Long Island Railroad's damage along the south coast of Long Island consisted mainly of numerous washouts between the Hamptons and Montauk. High water covered the third rail in places, causing loss of power on the Far Rockaway branch and the Port Washington branch between Bayside and Port Washington. The high-voltage transmission of the Long Island was somewhat interfered with on account of high wind. The New York Central suffered washouts on its Putnam division between New York City and Chatham. The West Shore, Lackawanna, Central of New Jersey, and Erie railroads had slight delays from high water, fallen trees, and other causes, but were relatively free from trouble.

New Haven Road Suffered Most

The New Haven suffered damage perhaps more serious and widespread than any of the other railroads within reach of the storms. The type of damage consisted largely, like that of the other roads affected, of washouts, bridge destruction, landslides and miscellaneous debris on the tracks. River and the tide waves did the same kind of damage to tracks and bridges, and also inundated miscellaneous electrical facilities, such as signals, drawbridge motors, shop motors, and station facilities. The areas affected were very generally distributed, the most serious damage being perhaps on the shore of Long Island Sound, especially between Saybrook, Conn., and Westerly, R. I., and the shores of Narragansett Bay and Buzzards Bay.

Views showing typical damage to railroads: (1) These boats were left high and dry outside the Central of Vermont freight terminal at New London, Conn. (2) Failure of a dam at West Warren, Mass., caused this washout on the Boston and Albany. (3) Bridge washout at Erving, Mass., on the Boston and Maine. (4 and 5) Examples of the extensive damage on the shore line of the New Haven, caused by the tidal wave that accompanied the storm

The New Haven is electrified between New York and New Haven over the Hell Gate Bridge, with overhead-trolley power distribution. While the storm west of New Haven was undoubtedly less severe than at other points, nevertheless it was very severe even in that territory; it is of interest to note that there was no damage to the traction-power transmission and distribution facilities. There were numerous grounds, or short circuits, on the system, caused by trees and other foreign matter blowing into the wires, but as soon as the debris could be removed, the individual circuits were re-energized and there was no train delay whatever due to traction-power failure.

The traction power is partially purchased and partially produced by the railroad. The railroad power plant at Cos Cob was subject to interruption on the evening of September 21 when the tidal wave hit that vicinity and flooded the condenser pit to a depth of five or six feet, covering the condenser pump motors and other equipment. Fortunately dual drive for the pumps was available and before the water was out of the basement, cleaning was under way, and the power plant was again fully functioning at four o'clock the next morning—in ample time to handle the morning commuter travel. During the outage at Cos Cob, traction power was supplied adequately from the Consolidated Edison (N. Y.) and the Connecticut Light and Power systems, and there was thus no interruption whatever in the traction power supply. When the Edison supply was curtailed, Cos Cob and the Connecticut Light and Power system were able to carry all the load required without inconvenience.

The communication system between New Haven and New York is in lead-covered cable throughout, either underground or supported on short poles, well guyed. There was thus no interruption of any kind to the communication service in that territory.

The New Haven experienced washouts at over 250 separate points, and slides at 21 points; 43 bridges were either destroyed or seriously damaged. The length of track actually washed out was about 17 miles, the maximum depth of washed-out track running to as much as 50 feet. The number of places where the tracks were blocked by houses, boats, trees, and other debris ran into thousands.

The tracks between New Haven and Springfield, Mass., were not seriously damaged, and operation started to Hartford from New Haven as soon as the cut east of New Haven station had been freed of water. The Connecticut River, however, continued to rise until the evening of September 23, and Springfield service north of Hartford continued to be interrupted by high water for several days. At this time also the small switch house at Hartford where electric power is received and distributed for the yard, station, and shop facilities in the vicinity of Hartford, was inundated and put out of service. There was fortunately an alternative supply for the Hartford passenger station, and therefore lights were not lost there.

Immediately after the storm, the evening of the 21st, work trains were started from as many points as possible, and within a day or two more than 5,000 men were at work. The men lived in camps and in camp cars and were, in general, fed on the job.

The main line of the Boston and Maine from Troy, N. Y., to Greenfield, Mass., was opened October 1, whence detour routes through Bellows Falls or White River Junction, Vt., were used for a time, to Boston.

The Boston and Albany main line through to Boston was opened for westbound traffic September 30, and eastbound October 1.

The New Haven on September 28 opened the old air line route from New Haven to Boston, through Middletown and Willimantic, for eastbound freight, and through Willimantic and Hartford for westbound freight. The shore line was available on September 24 for passenger service between New Haven and Saybrook, and between Boston and Westerly, the intervening territory being served by connecting busses on the highways. The extent of the bus transport gap was gradually reduced as reconstruction permitted, and through shore line service was established October 5. On September 30, through passenger service between New York and Boston, via Springfield, had been re-established.

Miscellaneous Electrical Problems

Miscellaneous railroad problems in the electrical field consisted in restoration of lights and power supply to stations and shops, drying out flooded motors and rewiring control circuits, re-establishing signal and interlocking facilities, and also, as has been indicated, restoration of communication facilities (which are taken for granted in normal times, but which are the *sine qua non* of railroad operation) as well as of emergency reconstruction such as existed, where tools, material, and supplies were wanted in the shortest possible time.

Salt-water exposure, of course, presented more serious problems with electrical facilities than fresh water, and it was found that submersion was not necessary to give trouble, but that salt water spray sometimes was fully as disastrous. It was necessary to insure that motors and other electric facilities were not energized until they were fully cleaned and dried out; failure to observe this rule in some instances caused considerable inconvenience.

The damage to wood-pole communication and power lines, though chiefly from contact with trees or other debris, showed the advantages of underground cable construction, especially when connections to such cables were either installed sufficiently high to avoid floods or when the pothead installations were properly waterproofed. Underground construction, of course, would have been of no advantage in washed-out territory, where the most serious railroad damage occurred.

Small portable gasoline-engine generating sets were very handy in supplying temporary emergency lights and small power requirements for local freight and passenger stations, and for floodlighting construction work at night, when power was not otherwise available.

It may be said that in general, except for the communication and signal power-supply circuits, the principal damage to railroad facilities was essentially *not* hurricane damage, but damage by water, fresh or salt, from the rivers and from the sea.

III—Hurricane Experiences of Power Utilities in Long Island

By E. W. DOEBLER

THE Long Island Lighting Company system extends from the Rockaway beaches to Orient and Montauk points on the eastern end of the island, although the main part of our territory is, of course, outside of the city of New York. This territory is a little more than 100 miles long and at right angles to the path of the storm, with a maximum width of about 25 miles and a population in the whole area of something less than 700,000 people. The system has three main generating stations, one at Far Rockaway on Jamaica Bay, one at Northport on the north shore of Long Island in Suffolk County, and our principal station at Glenwood Landing which is also on the north shore in Hempstead Harbor. These stations feed into two 66-kv circuits on steel towers running down the backbone of Long Island. The hurricane of September covered this whole area and disrupted the service in varying degrees and intensities in practically all of it. Although the wind velocities reached as high as 100 miles per hour, the damage to transmission and distribution lines was caused almost entirely by trees falling against the poles or across the lines, except in some cases where the poles were set in soil which became really drifting sand due to the high water.

We lost our first distribution substation at 1:15 p.m. on the day of the storm and at 5:00 p.m. practically all distribution substations except those connected with generating stations or directly connected with the 66-kv substations were without service. There were no particular engineering problems connected with the reconstruction of the transmission and distribution lines. The main job was applying man hours to the most vital points. To get an over-all picture of the problem, we made airplane surveys the morning after the storm. The more important substations were re-energized by 10:30 p.m. on the night of the storm, and all the substations except six small isolated stations on the beaches were back on the lines by 7:30 p.m. the following evening. As the substations were re-energized, the efforts in each district were directed to connecting waterworks, sewage systems, hospitals, telephone exchanges, and the company's three gas plants.

After these vital public services were reconnected, our man hours were directed to giving service to the greatest number of people with the least amount of work. No attempt was made to give individual service until this main heavy job had been completed.

Greatest Difficulties Caused by High Water

Our real engineering problems arrived after the storm had passed by. They were caused by water. The Far Rockaway plant experienced the high tide at 6:20 p.m., and the water was $2^1/_4$ feet higher than normal high tide. It was within a few inches of the condenser auxiliary floor. Comparing this height of water with what we might expect in the other two stations, we thought the worst was over. At 7:38 p.m. our Northport plant was shut down by a tide that had reached about $7^1/_2$ feet higher than normal high tide, submerging 28 motors in addition to voltage regulators, electrical auxiliaries, cable controls, and other equipment.

Finally, at 8:23 p.m., our main generating station at Glenwood was flooded. The tide rose to about 10 feet above normal high tide and submerged 72 motors, totaling 6,400 horsepower, in addition to cables, controls, rheostats, transformers, and other miscellaneous equipment; added to this was the loss of telephone service for 15 hours.

After the new Glenwood plant (at Glenwood there are two plants, an old one and a new one) was dewatered, the equipment that had been submerged was flushed with hot fresh water to wash out the sea water, thus reducing the amount of salt that might be deposited and preventing an excess of corrosion.

The rehabilitation of the equipment, and of the electrical equipment particularly, can be divided into three divisions: (1) motors, (2) control equipment, and (3) rheostats and grid resistors. The motors in the new Glenwood plant are wound generally for 2,300 volts. These were dismantled, again flushed with hot fresh water and then with carbon tetrachloride. The motors were then baked, the larger ones in homemade ovens in the plant, and all the

This typical view shows the general wreckage of summer homes at Fire Island Beach, Long Island, N. Y.

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rest in the service stations of General Electric and Westinghouse companies. After sufficient resistance to ground had been obtained, the coils were sprayed with insulating varnish. When reassembly had been thoroughly checked, the motors were given a two-hour test run and then considered ready for service.

The reconditioning of the control equipment was particularly troublesome, especially the equipment for controlling the 600-horsepower motors for the boiler feed pumps. It was finally found to be better to renew the small parts than to recondition them.

The rheostats for the generator and shaft exciter were dried by heating to almost red heat by means of torches. However, it took so long to dry out the neutral resistors that the station was returned to service with an ungrounded neutral. In this way, a 20,000-kw unit at the new Glenwood plant was back on the lines ten minutes less than three days after the shutdown and the 75,000 unit was back in six days and two hours after the shutdown.

In the Northport and the old Glenwood plants, the auxiliaries are run by 220- and 440-volt motors, so we thought we could take chances with these smaller motors that had been submerged. As a result of taking these chances, one of these units was on the line just after midnight the night of the storm. All the units of these stations were on the lines the evening of the day following the storm. It is true that a few small motors were burned out, but they were motors that could be replaced easily.

In addition to these items, we have a few other observations. Of course, it goes without saying that we are going to do what we can to prevent a similar occurrence in so far as the location and the design of the plants will permit.

Pole Damage Caused Mostly by Trees

Practically all of the 1,100 poles that were taken down during the storm were down because of falling trees. Our experience is that where there were no trees or where the clearance was good, we had no trouble, or very little.

We believe that everyone should have an emergency program for distribution lines, showing for each substation district the proper sequence of the restoration of service so that the most important locations will get service first. In case of a catastrophe like the shutdown at Glenwood, we believe authority should be delegated to one person so that decisions may be reached quickly. We also think that the work should be subdivided into small jobs and one man made responsible for one particular job. Frequent reports should be gathered and tabulated and bulletins issued at frequent intervals so everybody concerned can know the exact progress of the work. We observed that all the employees, no matter what their jobs, will work and continue to work beyond the limit of human endurance in order to make the best possible records for restoration of service; but to get the best results, we believe that the work period should be limited to at least a maximum of 12 hours after going through the first night.

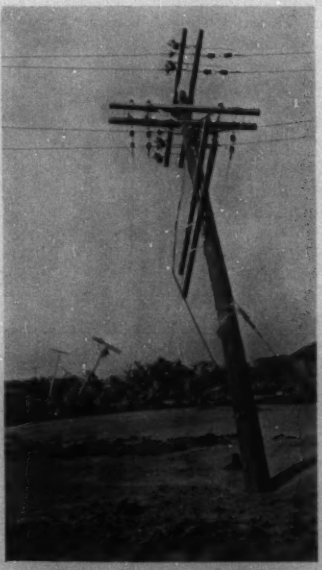
We are a little dubious about complicated electrical controls such as for the boiler feed pumps when they are subject to being flooded by sea water. If it is not practical to install the complicated electrical controls at a height beyond any possible flooding, it might be advisable to find a simpler method of control.

Public Relations During Restoration

One other problem which we believe is probably more important than the engineering problems is handling the public. Motors can be replaced, but it is not easy to replace a good feeling from the public. In our experience, we organized forces in the field to get information into the district offices where people were answering telephones and otherwise taking care of customers, keeping them up to the minute in the progress of reconstruction so that the best possible and the most intelligent information could be given to the customers in order that they might know what to expect. Most of them were interested not in whether they were going to have service the next minute but when they might expect it.

As a result of that program, we believe that we were accorded much greater tolerance from our customers and that there was a better feeling, even among the customers themselves.

One good thing that came out of the storm as far as we were concerned was this: There is often an unwholesome feeling between employees of commercial departments and operating departments, and in some places they seem like two different companies. We have had similar experiences, but after the storm was over, everybody recognized that everybody else's job probably was just as important as his. We have found a much better community of interest among all the departments as a result of this storm.



This Long Island pole line withstood the high wind, but the poles were displaced where the soil was weakened by highwater

IV—Hurricane Experiences of Power Utilities in Connecticut

By C. W. BROWN
MEMBER AIEE

EXCLUSIVE of the Cos Cob station (referred to in article II of this series) there are five steam generating stations along the Connecticut coast owned by three different operating companies. These stations are at Montville, New Haven, Bridgeport, Devon, and Stamford. As a result of the storm wave, the Montville and Stamford stations suffered outages because of flooded essential auxiliary equipment. New Haven and Bridgeport stations did not shut down, but did have a few non-essential motors flooded. At Devon, earth barricades excluded water from the station.

Following four days of torrential rains the Connecticut River rose 30 feet at the Hartford steam station. This was within 2 feet of the 1936 flood crest. The Hartford station, however, is bulkheaded to withstand a rise of 35 feet.

Throughout the state, modern hydroelectric stations with adequate dams and spillways were not materially damaged. Equipment was wet in some of them, and all had to reduce load because of high water. Several small, antiquated stations were destroyed, and these will not be replaced.

Wind damage was much more severe in the easterly part of the state than in the westerly part. A few towers in the Hartford-to-Massachusetts line failed at the ground line when the anchors on the tension side pulled through the saturated earth sufficiently to buckle the members on the compression side. These towers were easily righted temporarily by guying. There were no tower failures from wind in the westerly part of the state, but one tower did have footings washed out. At New London, on the east, about 6 per cent of the distribution poles went down, whereas in Stamford, in the west, only one-fifth of one per cent of the poles had to be replaced.

I shall refer now particularly to New London, but in general my remarks can be applied broadly to The Connecticut Power Company as a whole, and to a slight degree to The Hartford Electric Light Company.

Timing of Rehabilitation Work Important

Our problem was very much one of timing. For instance, during the first few days when the streets were completely blocked by fallen trees, we could not have used a great number of line trucks and crews if we had had them. At this stage, squads from the planning department and tree men were more important than linemen. As the streets were cleared, crews were built up by classes to salvage or remove equipment; to deliver poles and to set poles; to do normal line work; and to run services. As the work progressed line crews were released and service-running crews augmented. For these we worked in a great many house-wiring electricians. Most of our outside help came from Pennsylvania, Ohio, and Michigan. These men fitted themselves into our organization as if they had been with us always.

The things we did and would do again are as follows:

1. We had an emergency organization setup and adhered strictly to it—for publicity, public relations, planning, supervising, purchasing, accounting, and for carrying out the work. Some departments were transferred, or augmented, or specialized, while other departments had to be created to cover items peculiar to the emergency, such as arranging for rooms, meeting incoming crews and other matters.

2. We set the working schedule to hours that could be carried out day after day without undue fatigue, and permitted no deviation from the schedule. During the 1936 flood, we were not so careful about hours as we were following the 1938 hurricane.

3. We agreed promptly with the telephone company on the streets in which each of us was to set poles, regardless of which company was custodian.

4. We worked from detailed and up-to-date maps. By doing so we were able to reduce to a minimum the paper work required of foremen, without plant accounts suffering in any way.

5. We pulled butts and set new poles in old locations. These old locations, in most instances, came into being only after the issuance of applications, permits, and consents, and in accordance with statute, ordinance, and regulations.

6. We worked all primary lines dead. Our normal forces were increased tenfold, and the risk from live work was too great to take.

7. In spite of some criticism, we made services alive only when someone could give access to the building. We had no fires from this cause, but other territory did.

The methods we would change are:

1. We would avoid congregating large groups of men in a single restaurant. Even though meals were staggered to some extent, the danger was very real.

2. While in general we were able to keep ourselves supplied with line materials, the difficulty in securing some few items showed the advisability of making a shift in our purchasing policy so as to give business in normal times to nearby manufacturers.

3. We would be more prompt in our contacts with public authorities concerning some items. For instance, a great many helpful services to the community were performed by WPA, CCC boys, and others by assisting in clearing the streets. Their axes sometimes were used to the detriment of conductors, but we might have prevented this by anticipating it.

4. We would probably give more publicity to the importance of customers having their damaged services repaired. Some undue delays resulted from customers' neglect, in spite of newspaper bulletins.

Some forms of lack of co-ordination are difficult to anticipate. For example, in one or two instances public institutions through political appeal arranged with public authorities for temporary use of internal-combustion-

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engine generating sets, only to find after long hauls over difficult detours that our service already had been restored, or to find that the generators were not applicable.

The following general comments may be pertinent:

1. The remark was made several times after the storm to the effect that falling trees showed the disadvantage of lighting companies occupying joint poles with the telephone company when the telephone company used messenger and aerial cable. This comment was prompted by the fact that the pole is weaker than the messenger, and the falling tree often resulted in a broken pole. The thought, of course, was that with only the open wires of the lighting company, the conductor would break and these repairs could be made fairly promptly. There are two sides to this argument. The first circuit which was energized in New London and which became the first main feed for restoration of service, was a 350,000-circular-mil aerial cable. It lay in the gutter and was tangled in the branches of fallen trees, but was uninjured. In general, the storm did not change our ideas as to the advantages of aerial cable in particular locations, although some aerial cable was destroyed.

2. Pole lines would have given little trouble had it not been for trees and washouts.

3. Troubles with underground construction were in locations where transformers installed in building vaults were not of the subway type. Potheads, cables, and other apparatus in these vaults, as well as transformers, were damaged by flood water.

4. Uprooted trees in residential areas destroyed underground electric and gas services. There were not a great number of these, but they show that underground construction is not entirely immune to hurricanes.

5. Property damage of The Hartford Electric Light Company and The Connecticut Power Company amounted to approximately $650,000. This sum, even if hurricanes and other disasters occurred more frequently, falls far short of justifying, economically, underground construction in overhead areas. But another economic question is not so easily answered, namely, how much raising or protecting station, substation, and other equipment is justified? Within two years two floods in the Connecticut River Valley have exceeded crest records extending over a period of nearly a century. This problem is now being studied.

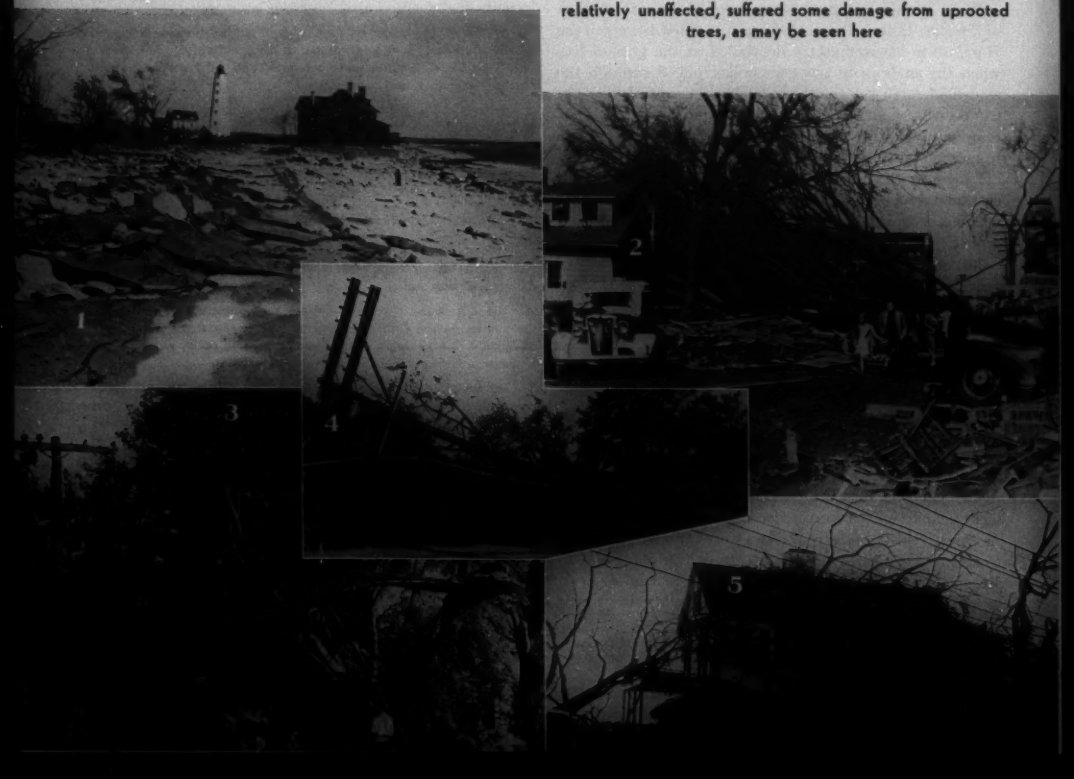
Figure 1. Along the shore at New London, Conn., the sea wall and highway paving were destroyed, and pole lines and water mains were completely washed out

Figure 2. Power lines were completely demolished in the general wreckage here, but may be seen intact in the background

Figure 3. This pole in Woburn, Mass., escaped the falling trees

Figure 4. Damage to this line in Milton, Mass., is typical of the tremendous damage to pole lines caused by falling trees

Figure 5. Underground gas and electric mains, although relatively unaffected, suffered some damage from uprooted trees, as may be seen here



V—Hurricane Experiences of Power Utilities in Boston Area

By T. H. HAINES
MEMBER AIEE

THE PATH of the hurricane disturbance over New England embraced the entire system of the Boston Edison Company. The wind velocity of the hurricane at the Blue Hill Observatory near Boston situated 500 feet above sea level approximated 186 miles per hour at 6:47 p.m. on the day of the storm and several sustained gusts of 111 miles per hour were recorded over five-minute periods. In general, the maximum wind velocity at the ground throughout our area was estimated to have been in the vicinity of 85 to 100 miles per hour. There was almost no rain in Boston although rain elsewhere resulted in extensive floods.

The Boston Edison Company supplies electricity to Boston and 39 other cities and towns in a contiguous territory west of Boston, embracing 600 square miles and having a population of 1,400,000 people. This area forms roughly a 30-mile circle with the City of Boston at the eastern edge.

Reaching the southern portion of our territory at about 5:00 o'clock, the storm progressed rapidly over the entire area and by 7:00 o'clock 166 of our 225 primary distribution circuits and a corresponding proportion of series lighting circuits were dead. Substantially all of our overhead transmission, except lines on cleared rights-of-way, were out due to line troubles. Only the d-c network and a portion of the a-c underground system in the City of Boston remained unaffected. Damage to power plants was quite nominal except for two coal bridges, one of which was wrecked beyond possibility of feasible repair and the other not so seriously but that it could be put back in service within a few days.

The following morning all of our own 110-kv transmission lines were found to be intact, although the southern line had been interrupted during the storm by the failure of six towers in the territory of the New England Power Company, due to softening of the earth footings.

The southern line is of double-circuit vertical steel construction in our territory, while in the New England Power end of the line, and in our northern line, the circuits are carried on separate semi-flexible H-type steel towers, the conductors being in a horizontal plane.

In one of our 66-kv wood-pole lines four poles were blown out of line by the wind near a swamp where the footings were softened by high water, but were not broken. At another location one pole was found broken at the ground and leaning. On another 66-kv line one wire was broken by trees. All 15-kv transmission lines, which are not on cleared rights-of-way, were out because of tree interference.

Our distribution system was found to be in a generally wrecked condition. Damage was due almost entirely to tree interference and, in general, distribution lines were unaffected by the wind pressure alone. These illustrations demonstrate the fact that the force of the wind, even though of extremely high velocity and sufficient to blow down many big trees, did very little damage to the lines where there were no trees or where the trees fell *away* from the wires. Trees falling *on* poles and wires, however, resulted in a vast amount of confusion and damage.

One unusual exception to the general type of damage occurred in a pole line consisting of 55-foot poles, some with nine double eight-pin crossarms. This line carries 44 primary and series lighting wires feeding four towns. All these lines were opened at the station soon after the first one tripped out during the storm. About five minutes later five adjacent poles in this line snapped. Two of these broke about 20 feet above ground at the telephone through-bolt, the others at lower points, allowing the heavy tops to fall into the street.

Five line crews and a supervisor worked under the existing incredible conditions of wind and darkness, lifted the fallen pole tops in unison, set them back upon the broken stubs, lashed the tops and stubs together with 30-foot poles, and guyed the tops—all without breaking or cutting the conductors. This feat was accomplished by 7:00 o'clock the following morning.

Although the serious hazard to the system of such congestion had been previously recognized, this experience clearly emphasized the need, and our budget now provides for placing such leads underground.

Reconstruction

On the day following the storm, the work of reconstruction of primary and secondary circuits began on a dawn-to-dark basis. Our normal line force of 253 men was expanded as speedily as possible to approximately 2,000 by additional line crews and labor of all descriptions recruited from various local sources, as well as from utilities outside the New England area. An emergency organization was quickly established with field units suitably located for the purpose of co-ordinating the restoration activities of the entire area.

Thirteen days after the storm, upon practical completion of primary and secondary restoration work, customers still without service were invited by an announcement in all newspapers to notify the company. Calls received indicated that only 660 were still without service, and two days later these were reduced to less than usually occurs on a normal day due to blown fuses and minor trouble. The restoration of the series lighting load occupied another two weeks.

In spite of the fact that it was necessary to use a great

Essential substance of an address presented at a general session of the AIEE winter convention, New York, N. Y., January 23–27, 1939.

T. H. HAINES is superintendent of transmission and distribution of the Boston Edison Company, Boston, Mass.

many inexperienced employees on this work, accidents were comparatively few.

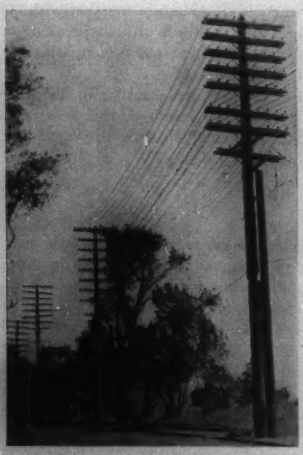
Although the experiences described are those of the Boston Edison system, the overhead systems of utilities in other Massachusetts and Northern New England communities in the path of the hurricane were similarly affected. Additional damage occurred along the southern coast of New England, where tidal waves flooded large areas. In the City of Providence, R. I., for instance, electrical equipment was completely submerged in salt water, necessitating thorough washing and drying out before service could be restored.

Analysis of Line Construction Experience

Although the effect of the 1938 hurricane on our overhead lines was the most severe since the great sleet storm of 1921, careful analysis of the disaster convinces us that there was no outstanding weakness in our line construction, and had it not been for falling trees the terrific wind velocities would have caused only negligible damage to normal distribution construction.

Observations made from the storm experience may be classified in two types—administrative and technical. Of the former, the following are most prominent:

1. It is advisable to have in readiness a general emergency organization plan to facilitate quick action with a minimum of lost motion.



Five poles in this line at Woburn, Mass., snapped off, but conductors remained intact. Line crews, working under the extreme difficulties imposed by wind and darkness, lifted the pole tops in unison, set them back upon the broken stubs, and lashed them to 30-foot poles—all without breaking or cutting the conductors

Doubtless many errors of judgment could have been avoided and time saved if a plan had previously been in existence.

2. Judicious use of paid advertising to tell the public the truth of our situation paid dividends in complete public understanding of our problem and improved public relations.

3. If a line organization is to be expanded from five to ten times in a few days, quarters and facilities, both in the office and for stock handling, must be available to provide for the increased personnel or a decentralization plan should be placed in operation quickly. Our

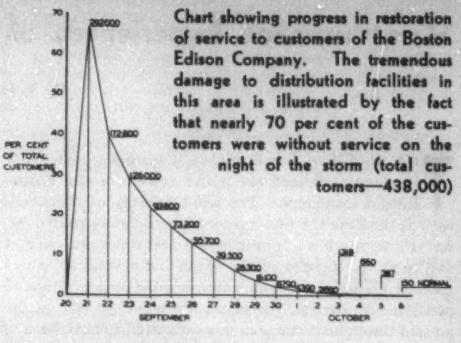


Chart showing progress in restoration of service to customers of the Boston Edison Company. The tremendous damage to distribution facilities in this area is illustrated by the fact that nearly 70 per cent of the customers were without service on the night of the storm (total customers—438,000)

greatest difficulties and congestion were experienced where the operating quarters were just adequate for normal conditions.

4. An organization separate from the line department placed in the field to maintain contact with local officials and the public, and divert such contacts from the ordinary operating and construction forces is essential.

5. The existence of local line-construction contracting forces which can be expanded quickly under stress and which are familiar with locations and local methods was amply justified.

6. Supervision for imported line crews and others was an urgent need, and how to provide this at such a time has not been solved.

7. Two-way radio communication doubtless would have been a valuable aid in reducing the time to restore service. In at least one instance carrier current over transmission lines proved valuable as a means of communication in the absence of telephone service.

8. Temporary reconstruction regardless of appearance, but with due regard for safety, may be the more expensive method, but it is essential for quick restoration.

From a technical standpoint the following is presented:

1. More extensive standardization of engineering design, construction methods, and materials used in our industry would assist greatly when crews are brought from a distance, not only because they could work more expeditiously, but also because they could bring their own supervision which could act then with little or no local help. Furthermore, material in national use is most easily obtained.

2. Our own overhead construction practices—selection of poles, depth of pole settings, wide primary conductor spacing—with a few minor exceptions satisfactorily withstood the impressed wind loads. No reasonable construction could have withstood the falling trees.

3. The concentration of too great an amount of construction and equipment upon certain individual poles which can be destroyed easily by a single tree or by other accidents should be avoided where practicable.

4. Multiple street lighting registered an advantage as it was restored simultaneously with customer services while the series circuits remained dead until all other service was reconnected.

5. Automatic line splices and solderless tap connectors were an invaluable help in speeding the reconstruction work, not only with the line crews, but also with the inexperienced wiring contractors who were pressed into service.

We present these observations and analyses to the industry in the hope that our experience may in some way assist others in lessening the effect of any similar catastrophe which it may be their misfortune to encounter.

VI—Hurricane Experiences of the Telephone Companies

By W. H. HARRISON
FELLOW AIEE

EXPERIENCES of the telephone companies are naturally much the same as those already described. The aftermath tally showed that more than one-half million telephones were put out of service—in the New England States about 30 per cent of the telephones in that area. Through the destruction of toll lines, the storm temporarily cut off telephone communication with the outside from over 200 towns. The total damage to telephone plant was in the neighborhood of ten million dollars.

The story of restoration—the immediate provision of emergency services—the handling of emergency supplies in unprecedented quantities—the augmenting of forces locally to supplement the normal forces—and the mobilization of forces from other areas—all are replete with engineering interest and are very intriguing; but it would not be appropriate to attempt to tell the whole story here. A few facts will give a sketchy idea of the situation.

Some of the materials required to repair the damage were:

3,500,000 feet of lead-covered cable.
54,000,000 feet of paired wire.
7,000,000 feet of stranded steel cable for guys and supporting cables.

Local construction forces were expanded from 3,000 to 5,000. In addition, 2,400 highly skilled linemen, cable splicers, and installers, and over 600 fully equipped construction trucks and other special motor vehicles were brought from 14 other telephone companies as far south as Virginia and as far west as Nebraska and Arkansas.

Of striking significance in the prompt restoration of service was the traditional Bell System background of standardization of materials and methods. This standardization greatly facilitated the collection of large quantities of suitable supplies and made possible maximum effectiveness of the men who came from many parts of the country. The striking effectiveness of these measures is a great tribute to the engineers who long ago, by their recognition of the value of standardization, laid the broad foundation for this effective work.

In every disaster much is learned with regard to formulating plans and caring for specific situations. Of interest in this specific situation, there had been serious floods in much of this territory in 1936. The experience at that time pointed to certain precautionary measures and we know of no case where these did not prove effective in the present situation. For example, while the water rose 5 feet above the ground-floor level of the main telephone building in Hartford, Conn., it was successfully kept out of the building by bulkheads about the doors and windows, provided since the 1936 flood. Also, at various places where lines had been carried away due to the failure of bridges or other forms of river crossings the restored lines did not fail.

Over and above all these more or less specific points, which I might say are somewhat routine, lies a broad engineering fundamental vividly illustrated by this whole experience.

Engineers by their work have made a pattern of life that has come to make individuals and communities dependent to a large extent in their day-to-day activities and mode of living on the proper functioning of the services of power, transportation, and communication. Having done this, they have seen their works fall before the fury of nature—have seen the utter disruption of the organized scheme of life, with all the anguish that goes with such disruption.

In the light of this experience an engineering fundamental of first magnitude presents itself, and one that offers a long-range problem that is going to call for nicely balanced judgment, both on the part of the engineer and the management. This fundamental stands out clearly—dependability of service, and specifically the degree to which dependability soundly and wisely can be built into the physical plant.

It is trite to say that dependability is fundamental to good service, that it is of prime consideration in the design, construction, and operation of all communication, power, and transportation facilities. On the other hand, it would be foolhardy to assume that any man-made structure could completely withstand the fury of the elements, as typified by this storm.

Consider the circumstances. For four days rain was progressively heavier. It totaled between five and ten inches at many New England points. At some places more than six inches of rain fell in one day. As a result large rivers were brought to flood stage and small brooks and streams became raging destructive torrents. And then came the hurricane—then the seas. Wind velocities

After the flood of 1936 in Hartford, Conn., bulkheads were built for the doors and windows of the telephone building nearest the river; these successfully kept the water out of the building during the flood accompanying the 1938 storm

Essential substance of an address presented at a general session of the AIEE winter convention, New York, N. Y., January 23-27, 1939.

W. H. HARRISON is vice-president and chief engineer of the American Telephone and Telegraph Company, New York, N. Y.

as high as from 120 to 180 miles per hour have been reported. Raging flood and tidal water inundated important sections of many communities. Our services extended over the entire band of the storm and we can definitely trace the relationship of high wind velocities and resultant damage.

Another important circumstance, and bearing particularly on engineering consideration, is that nothing like this had happened in this area since the year 1815. Obviously, to build plant to be unyielding to the sea and to be hurricane tight against such occurrences at century intervals would be as unsound as to ignore them altogether. Thus a challenge is presented to the engineer taxing his best judgment: on the one hand, not failing to take every reasonable precaution in the future design of the plant, such as the avoidance of known exposures, the provision of alternate routes, the use of emergency restoration facilities of every conceivable character, adequate emergency operating routines; and on the other hand, not to be led by the tragedy of the storm to recommend extreme construction and operating procedures such as wholesale substitution of underground for aerial plant, which would obviously not be in the public interest.

This, it seems to me, is the broad lesson that we draw from this experience and the challenge presented to the engineer.

A Tribute to the Restoration Forces

It was my good fortune to have been in the midst of the restoration work. It was comforting and inspiring to see how the men and women of all service agencies responded to the call, each presented with a trying problem of his own, but ever ready to lend helpful and effective cooperation to those in other utilities, and all motivated with the common objective of maximum service to the community in this period of great distress. I know we in the telephone end could not have done our job had we not had the help of others, including the highway and other public agencies.

The final measure of any man's work is: Has it been for mankind? A grateful public has put the mark of approval on the work of the men and women of the utilities and transportation groups in the stricken area. My admiration for them knows no bounds. Frequently when we fail of expression we turn to the pens of immortals.

Two lines in one of Kipling's poems "Sons of Martha" beautifully express the work of these men and women:

Not as a ladder from earth to heaven, not as a witness to any creed,
But simple service simply given to his own kind in their common need.

After the bridge at Chicopee Falls, Mass., washed out, taking with it two telephone cables, the Coast Guard fired the first line across the 700-foot flood with a Lyle gun. What followed is shown above—temporary twisted pairs spanning the river, and a lineman riding another suspension cable preparing to pull across a full-sized cable

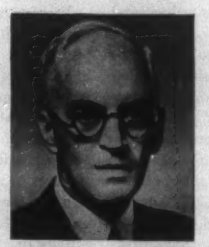
This damage to overhead telephone lines in Spencer, Mass., is typical of that caused by falling trees throughout the affected area

The Engineer's Social and Political Relations

By JOHN C. PARKER
PRESIDENT AIEE

Remarks made by President Parker at a general session of the recent AIEE winter convention on the subject of the social and political relations of professional bodies are presented here.

AT A GENERAL session of the AIEE, it is not inappropriate that the president of the Institute lay before the members for their personal consideration some of the circumstances surrounding the social and political relations of professional bodies.



I assume that the technical aspects of engineering work are of the very essence of the Institute's existence. As there can be no science of medicine without biochemistry, physiology, and anatomy, so there can be no profession of engineering without experimental research and theoretical analysis into the operation of the forces and materials of nature as combined in devices and structures created for the service and convenience of mankind.

Through a long period of years—as far back as I can recall—there has been an insistence on the part of a large group of engineers that our technical papers and discussions were a narrow activity; that by one device or another we must devote ourselves to the service of government, to demanding professional recognition for engineers, to improving the economic status of the engineer. There can be no quarrel with some, at least, of the insistence on a broader conception of our professional duty, however much opinions may differ as to the methods to be employed. There is, however, a perfectly sound and valid, indeed an inescapable criticism that must lie against any thought that the scientific aspect of the work of our professional societies is negligible or even of secondary importance. We cannot hope for recognition except as we merit it, and we shall not be found to merit recognition if we ourselves fail to recognize a fundamental duty that we bring about a widening and a deepening of our knowledge of applied natural law and a fuller dissemination of that knowledge.

However much we should do beyond this, this is essential.

The work of the engineer, of course, differentiates itself from that of the pure scientist, the mathematician, the physicist, the chemist, in that we are concerned primarily in the direction of the forces and materials of nature for the convenience and comfort of mankind.

While the most advanced engineering is profoundly concerned with the discoveries and developments in the field of pure science, engineering as engineering, nonetheless, is concerned primarily with the directive function. The direction of pure science toward social objectives must find a physical embodiment in machines, devices, structures, and circuits. To this embodiment we give the name of applied science. The function of application is what sets the practicing physician or the clinical investigator apart from the researcher in pure science. Similarly in engineering, the practitioners differentiate themselves from the mathematicians and physicists through an emphasis on the operations of scientific laws in tangible embodiments designed and produced for utility.

Still we are in the field of theory. To this, in the spirit of realism, must be added the criteria of experience. It is not enough that one of our engineering societies should concern itself with the application of pure science through design to the development of structures, circuits, and devices, but we must, as well, know how these work out in practice in order to appraise how fully we have directed the materials and forces of nature to the service and convenience of mankind, in fact as well as in intent, and so a reasonable portion of the literature and of the discussions in our Institute properly must concern themselves with the so-called practical aspects of engineering, albeit these latter are no more practical in fact than the design, the research, and the analytic processes which are fundamental to all practice.

So far, the work of the engineer is entirely technical. If our technical work is not to miss its objective of serving the convenience and comfort of mankind, it must do so under terms and conditions laid down by the society which it purports to serve. If men in free society do not willingly contribute a portion of what they create to enable a realization of our nicely developed technique, to that extent we shall have failed to accomplish the very service for which engineering exists.

Our engineering processes are, by definition, economic in character. Indeed much of the finest engineering that is done is directed toward the discovery of new materials, toward the evolving of new theories or the extension of old ones, toward a greater refinement in application and assembly and management of engineering devices guided and controlled by the application of economic principles.

An engineering paper does not cease to be an engineering paper because it takes into account a nice balancing of fixed and operating costs, nor will it be entirely amiss to evaluate the social contributions of an engineering development against what must be taken from society in order to produce it.

Our engineering is not done in a vacuum. It is per-

formed in a very real society controlled by the actualities of life.

Because of these considerations it seems to me eminently proper, indeed unavoidable, that the Institute should concern itself with the impingement of economic factors on technical problems and that the members of the Institute should have made available to them every stimulus to a fuller awareness not only of the economic but of the social implications of the work of the engineer. Such a meeting as this general session is directed to precisely that point of view, not that we should render our technique superficial through an amateurish dabbling in the economic science, but that we should give perspective to our professional work through an appreciation of its values and its limitations.

Because of a happily increasing recognition of the importance of engineering process in an increasingly industrial society, because of a wholesome professional restlessness on the part of engineers, it comes about quite naturally that members of the profession are more and more anxious to take part in the social, the economic, and the political affairs surrounding them. In that this broader outlook keeps us from being mere technicians, it is a hopeful sign. We must, however, be on our guard that we do not jump from one form of narrowness into another—from the assumption that because we are engineers we need not concern ourselves with anything other than engineering to the equally fallacious assumption that because we are engineers we are able to speak with authority on any problem that has an engineering aspect.

This modern society of ours has very few aspects that are not concerned, first or last, with engineering, and to assume that as engineers we can bring within the scope of our societies every matter that involves engineering would be almost tantamount to saying that engineers are prepared to take over the governance of society.

The particular knowledge of the engineer and the engineering method of approach are of extreme value and should be available to society in the meeting of each of its problems which has an engineering content. Indeed I doubt whether there are any social problems in which the objective factual methods of the best engineers are not of value. On the other hand, the very application of the engineering method must tell us that even in primarily engineering projects there are features of critical importance quite outside the specialized expertness of the average engineer, or indeed of the engineer as an engineer. May I hazard the suggestion that on many of the most acutely controversial issues involving engineering works the real problems are neither scientific nor those of the engineering profession, but rather that they are primarily matters of social philosophy in which other groups may be vastly more expert than are the engineering societies.

Whether these other groups be organizations for social improvement, for political research, or for the practical execution of social and political philosophies, it is through them, rather than through our professional societies, that engineers of the broadest interest can give expression to their sense of social responsibility.

Wisely the Institute has insisted that, neither directly nor through its agencies, will it commit itself to activities outside the field of professional engineering. Since it is made up of large groups of valued members who may, with reference to any social philosophy, constitute a minority, while at the same time they are as able and devoted members of the profession as any numerically preponderant group, it is not deemed the part of proper professional conduct to make difficult for them the privileges and the rights of membership, nor through a dissipation of our resources to deprive of the full benefits of membership those equally devoted and important members of the profession whose interests are primarily in the field of professional discussions and personal contact for mutual stimulus in the technique of engineering.

On the other hand, those engineers who are qualified and inclined to render the profession serviceable to the economic and social objectives of society should be stimulated to do so in collaboration with nonengineers, both informally and through groups organized for such special purpose. If the socially or politically minded engineer will bring into his association with lawyers, social workers, economists, and civic organizations, or even into the pressure groups frankly organized for some specific purpose, something of his special knowledge, his logical training, his intellectual integrity, he can accomplish things which would be denied to him working only in an engineering organization. If there is anything in our profession worthy of respect, he will bring about, through this process, a social recognition of our professional merits, a greater understanding of engineering, and an influence of the engineer on the minds of men and on their legislative enactments and administrative processes.

Aerial view of the largest oil-tool manufacturing plant in the world, to which an inspection trip is scheduled during the forthcoming AIEE South West District meeting at Houston, Tex., April 17–19, 1939. The plant is owned by Howard Hughes, well-known flier and motion-picture producer

Frank Baldwin Jewett—John Fritz Medalist

By KARL T. COMPTON
FELLOW AIEE

The qualifications of the 1939 recipient of the highest American engineering honor are those of a leader, a statesman, and a nobleman of science

AMONG politicians there are few real statesmen, among the aristocracy few true noblemen, among the masses of men few leaders. Ever since I have known Frank Baldwin Jewett I have thought of him as one of that very small group who are the leaders, statesmen, and noblemen of science. I rejoice in this opportunity to say publicly this which I have long thought in private.

Not all leaders are statesmen. Willard Gibbs was a leader in the advancement of science, Beethoven was preeminent as a composer of music, and Mark Hanna was a great politician, but we do not think of them as statesmen. On quite another plane, Cortez in his conquest of Mexico and certain political bosses and racketeers were powerful leaders, but they were not statesmen. Statesmanship implies wise and farsighted leadership toward ultimate social welfare, based on fundamental principles rather than opportunism. Wisdom, energy, and altruism characterize statesmen.

Neither are all statesmen noblemen; for statesmen are not necessarily men of culture, of unselfish consideration of others in their personal relations, of unswerving loyalty to high principles in their personal lives. A father's ambition might be for his son to become a statesman, but a mother's love would hope that he become the kind of a person whom I call a nobleman.

With these distinctions in mind, it is not strange that few men can qualify outstandingly in all three directions. But Frank Jewett has been the leader in building up a great technical and research organization. He has been a statesman in his effective participation in the councils of science, engineering, and industry to make them of the greatest possible benefit to humanity. And he has been so unfailingly loyal and helpful to his host of friends and colleagues, never counting the cost to himself but considering only their best interests, that these friends will assuredly join with me in dubbing him a nobleman.

Frank Baldwin Jewett comes of a long line of New England ancestors, the earliest having settled in Rowley, Mass., in 1632, only 12 years after the landing of the Pilgrim Fathers. These ancestors played active roles in the civil, social, and religious life of New England throughout the colonial days and the early period of the republic. Among his great-uncles was a librarian of the Boston Public Library and a publisher who, among other things, published the first editions of "Uncle Tom's Cabin." My genealogical research has not been carried to the point of tracing the medalist's family connections with the 47 Jewetts appearing in the Boston telephone directory, but it is reasonable to assume that these are living evidence that the prominence of this Jewett family in New England still persists.

Frank Jewett, however, came from the more adventurous branch of the family, which went westward, and still westward to the newer lands of opportunity. His immediate forebears settled in Ohio, at Cincinnati, and then his parents, Stanley P. Jewett and Phebe C. (Mead) Jewett, moved to California. Frank Jewett was born in Pasadena on September 5, 1879.

Professional Education

His first professional education was in the field of electrical engineering at the Throop Polytechnic Institute, which later became the California Institute of Technology, and he graduated with the bachelor of arts degree in 1898. Even then he demonstrated his lifelong interest and faith in fundamental science, and his quality of not being satisfied with less than the best that was possible; for he went for advanced study in physics, mathematics, and chemistry to the vigorous young University of Chicago, to which Professor Michelson had brought especial prestige and opportunity in physics. Here he received the degree of doctor of philosophy in 1902. During his last year at Chicago, he was research assistant to Professor Michelson, who was then developing his echelon spectroscope and building his famous dividing engine for ruling large diffraction gratings. Here also he formed the lifelong friendship with Robert A. Millikan, then an instructor in physics at the university. In the past 25 years there has been scarcely any far-reaching national program in science for human welfare or for national defense but has found these two men as colleagues in the planning and executive councils.

Jewett's final stage of formal education was secured at the Massachusetts Institute of Technology where, from 1902 to 1904, he studied advanced electrical engineering

Full text of an address delivered at the John Fritz Medal presentation ceremonies during the AIEE winter convention, New York, N. Y., January 26, 1939.

KARL T. COMPTON is president of Massachusetts Institute of Technology, Cambridge. He was born at Wooster, Ohio, September 14, 1887, and received his formal education at the College of Wooster and Princeton University; many honorary degrees have since been conferred upon him. After serving as instructor at the College of Wooster and Reed College, he became assistant professor of physics at Princeton in 1915, and in 1929 was made chairman of the department. In the following year he was appointed president of MIT. Doctor Compton has been active in the National Research Council and the Science Advisory Board, among other organizations, and is a member of various technical societies. In 1931 he was awarded the Rumford Medal of the American Academy of Arts and Sciences.

and was an instructor in physics and electrical engineering. These were exciting fields in those days, as now. MIT was in close association with the developments in electric power engineering under Elihu Thomson, and the head of the physics department, Professor Cross, was a friend and frequent consultant of Alexander Graham Bell, whose company then had its headquarters in Boston. Of course it is Jewett's innate ability and thorough fundamental training which have brought him to the top of the communications development field, but it was this early association between MIT and the telephone company that gave him his initial direction into it.

Doctor Jewett

In this field of electrical communications, the loading coil had recently been invented and showed promise of greatly extending the feasible range of telephonic communications. The mathematical and physical researches of Doctor G. A. Campbell had proved the enormous advantage of attacking this and similar research and development problems with the aid of the most powerful tools of mathematics and electrical science by men thoroughly trained to use them. Imbued with this conviction, Doctor Hammond V. Hayes, then chief engineer of the American Telephone and Telegraph Company, turned to MIT to find the best possible combination of ability and training, and selected the young Doctor Jewett for an association with the company which has been uninterrupted since 1904.

Advancement in His Profession

To this work, Doctor Jewett brought not only scientific training and ability, but also enthusiasm and a marked gift for organization and administration. To these qualities were added also a remarkable intuitive faculty for sensing the directions of most advantageous experimentation and development. If to these qualities we add his keen judgment of men, ability to inspire loyalty, and the highest integrity, it is not difficult to understand Jewett's steady and rapid promotion to ever more important positions of responsibility.

Within three years after his employment by the company, he was put in charge of the electrical department, and shortly thereafter was made transmission and protection engineer; directing the work which led to phantom loading, and the loading of large-gauge open-wire circuits, and the development of phantom-duplex cables. In 1912 he was made assistant chief engineer of the Western Electric Company in New York, where most of the research and development work of the American Telephone and Telegraph Company was being concentrated. Four years later he became chief engineer, in charge of all scientific development and also the engineering work connected with the manufacturing activities of the Western Electric Company. In 1921 he was elected vice-president and a director, and in the following year he was put in charge of all the manufacturing, sales, and distribution activities of that company in America. In 1925 there was some reorganization of the American Telephone and Telegraph Company and Doctor Jewett became vice-president of that company, and a director of its long-lines department, and also president of the Bell Telephone Laboratories which were then formed as the central research organization to serve the entire system.

The marvelous development of the art of electrical communications within our lifetime is in its major part the product of Doctor Jewett's work, planning, and supervision, aided and implemented by his remarkably able and loyal army of colleagues in laboratory and office. After the loading coil came the vacuum-tube amplifier and its uses in telephony, wireless, and radio. These made possible the transcontinental telephone lines. Permalloy enormously improved the submarine cable lines. Carrier waves enormously increased the carrying capacity of existing lines. Transoceanic telephone communication by radio was established in 1927. The automatic dial system was developed and introduced without confusion. Radiotelephony, wire to wireless broadcasting, sound accompaniment to motion pictures, wire and wireless transmission of pictures, teletypewriters are all new products in wide use, while television and radically new types of transmission lines are among the current developments. Every one of these has, in turn, involved literally thousands of investigations systematically planned for years in advance of a product perfect enough to meet the requirements of public use.

It seems to me that three features uniquely characterize this story of development of an unequalled public service. Firstly, there has been unswerving adherence to the primary subject of electrical communication of information, whether by dot and dash, by word, or by picture. Secondly, there has been steady devotion to the ideal of giving the very best possible service to the public and sparing no efforts to improve this service. Thirdly is a peculiar

characteristic of the telephone business: Every new subscriber must be provided with possible connections to every other subscriber; hence the tremendous emphasis on automatic switching, multiple messages over wires, and the like, which alone prevented the costs of universal interconnection from soaring as the number of subscribers has increased. It is now possible for you or me to be connected for speech with about 97 per cent of all the telephones in the world!

Public Services

Turning now to Doctor Jewett's *pro-bono-publico* activities, which have been legion, but a few of the most important ones can be mentioned. He was active in forming the National Research Council, set up by the National Academy of Sciences as a measure of national defense at the request of President Wilson in 1916, and he served for several terms as chairman of its division of engineering and industrial research. As a lieutenant colonel in the Signal Corps during the great war, Doctor Jewett took a leading part in the development of communication devices for both Army and Navy. As one of the most active members of the Science Advisory Board, appointed by President Roosevelt during the severest depression years, he gave particular attention to military and naval problems, to development of a co-ordinated research program for the American railroads, and to the safety of ships at sea in fog. When, in this year 1938–39, the Army Air Corps seeks help on certain technical problems, and the National Resources Committee wants to know what industry is doing in the line of research, of course Doctor Jewett is again called upon for still more service.

That these are only a few among his many public services is indicated by some of his other memberships: policy committee of the National Research Council, past president of the AIEE, British Institution of Electrical Engineers, New York Electrical Society, Society for the Promotion of Engineering Education, American Philosophical Society, Institute of Radio Engineers, American Association for Advancement of Science, American Physical Society, Acoustical Society of America, and American Society of Arts and Sciences. He is a trustee of the Carnegie Institution of Washington, the Woods Hole Oceanographic Laboratory, and Tabor Academy. He is president and trustee of the New York Museum of Science and Industry, and a life member of the Corporation of the Massachusetts Institute of Technology.

Honors and Medals

Naturally this John Fritz Medal is not the first honorary recognition of so distinguished a career. At least nine universities have made him honorary doctor of science, engineering, and laws. He has received the AIEE Edison Medal in 1928, the Faraday Medal of the Institution of Electrical Engineers in 1935, the Franklin Medal of the Franklin Institute in 1936, and the Washington Award last year. From our government he received the Distinguished Service Medal, and from the Japanese government the Fourth Order of the Rising Sun in 1923 and the Third Order of the Sacred Treasure in 1930.

I have sketched Doctor Jewett's career, mentioned some of his public services, and listed some of his honors. I have not mentioned, on the more personal side, the multitude of friends and colleagues whom he has helped by advice and example. Many have had experiences similar to my own. I have gone to him in perplexity over some personal problem and come away with clarified vision and courage. It is for this reason that I am especially grateful to have had this opportunity to say these words about my friend and colleague, Frank Baldwin Jewett—leader, statesman, and nobleman of science.

Illumination Notes*

Conditioned Reflex and Traffic Lights. When through experience a new stimulus becomes effective to produce automatic response, the neural mechanism producing it is called a conditioned reflex. Pavlov produced conditioned reflexes in dogs by associating for them the ringing of a bell or tapping on the skin with immediately thereafter receiving food. After such conditioning of reflexes, the bell or the tapping would suffice in itself to produce a flow of saliva. In driving an automobile, the shift of the right foot from accelerator pedal to brake pedal, or vice versa, as traffic conditions call for deceleration or acceleration, becomes almost automatic and largely unconscious. The introduction of traffic lights created a new stimulus to that response and thus a conditioned reflex.

Now Pavlov found that by creating a second conditioned reflex, antagonistic to the first, the dog could be made highly nervous, and soon would lose all conditioned reflexes. Howard B. Fabing, in a report published in the *Journal* of the American Medical Association, in September 1938, points out that traffic lights result in just such a collision of conditioned reflexes. A driver approaching a traffic light showing green, and so proceeding under the "go ahead" stimulus, may find it suddenly change color and receive a quick conflicting stimulus; or, even if it does not change, he knows by experience that a change is possible. The report shows that this collision of conditioned reflexes does result in nervous strain, through an "anxiety neurosis in miniature," followed by a bodily reaction of exhaustion.

The realization, shared by most engineers, that present traffic signals are far from perfect, is strengthened by this showing that they are psychologically bad, and this should lead to increased striving after improvement. In the meantime we must perforce endure the lesser evil of collision of conditioned reflexes to escape the more serious disaster of frequent collision of cars.

* Contributed for the AIEE committee on production and application of light by L. A. Hawkins (A'03, M'13) executive engineer, research laboratory, General Electric Company, Schenectady, N. Y.

Graduate Training for Engineers

By L. W. W. MORROW
FELLOW AIEE

Questioning the value and adequacy of post-graduate engineering courses as commonly conducted, this article tosses a verbal bombshell into the laps of educators. A symposium of solicited comments reflecting the opinions of representative industrialists and engineering educators is scheduled for presentation in the next issue; other brief comments are invited.

WHAT BASIS is there for proposing to give graduate training to engineers? Does this program originate in response to the demands of industry or does it spring from the minds of engineering educators? What facts justify a student in enrolling for graduate work or warrant an engineering college in embarking upon this expensive and difficult undertaking? These questions are pertinent to a discussion of graduate training for engineers.

A study of the market for engineers who have taken graduate work leads to the conclusion that industrialists offer no earmarked inducements to men who take this training and do not think that it would be profitable to employ them. One reason for this condition is that engineers with graduate training have no establishment or position as a professional group in industry. Another is that industrial leaders have not thought about this type of engineer and have had insufficient experience with them to formulate practices and policies. Only executives of a few large corporations, whose activities are based upon advanced technology, have considered such a program and most of these doubt the competency of the colleges to give adequate training. They prefer to hire four-year graduates and then develop them in their own organization. The majority of managers say the specifications for training are so varied and the number of men needed so limited that it is inadvisable for the colleges to undertake the work.

Some specific comments are given: A director of research and development in a large manufacturing company says, "It is foolish for engineering colleges to give graduate work. We need a few men with advanced training each year and select them from the doctors in mathematics, physics, and chemistry, and even here we pick those who have made specialized studies in particular fields of science. Engineering colleges would have to revise their undergraduate as well as their graduate curricula to produce men with an equivalent knowledge and training in the time available. We need graduate scientists but not graduate engineers."

A manager of a large engineering department concerned with the design and development of complicated machines says, "We do not need postgraduate engineers. Most of the four-year students we get now are so theoretical and impractical that we find it difficult to break them in. Let the colleges give a better undergraduate course before they undertake graduate work."

Another comment is by a director of engineering: "We doubt the ability of the colleges to give graduate work that would help men in their work with us. We prefer to take four-year men and train them by having our own specialists teach them the theory and practice involved in the technological aspects of our business. No college teacher could keep up-to-date on developments or have the data and facilities that our specialists have at hand. In my opinion it would be a waste of time for the colleges to give graduate training."

An engineer who is president of a large enterprise says, "I believe it would be a good thing for the engineering colleges to give graduate training to a limited number of high-grade men. But I do not think this graduate work should be entirely in engineering and science. We need men in industry with a training that will enable them to solve management, financial, and public relations problems, and I think the four-year engineering students with their technological background and with a method of attack peculiar to engineering offer the best possibilities for developing into leaders of industry if given a well planned graduate training." Other comments may be had in many quarters supporting the conclusion that the present market for graduate engineers is limited and highly specialized.

We cannot agree, however, that these comments are competent or conclusive. There is a broader perspective and a greater depth of thought to be applied than are exhibited within the narrow compass of these individual opinions. Yet, if these are the opinions of employers, why do the engineering educators wish to institute graduate work? Possibly their reasoning is based largely upon the infiltration of so-called cultural courses in the undergraduate curricula and the great depth and scope of technological knowledge now recorded and now needed by engineers in industry. These educators believe that more time must be devoted to training a limited number of specially qualified students so that they may be able to do more competent and more fruitful technological work in industry.

Some engineering educators have an idealistic concept for graduate work; they see the need of society for a highly trained and a broadly trained man to lead the nation toward a better way of living and a better conduct of national affairs. They base their program for graduate training on possibly too ambitious an idea of the place and the competency of the engineer in modern life.

Full text of an address delivered before the Society for the Promotion of Engineering Education, New York, N. Y., December 10, 1938.

L. W. W. MORROW is western editorial director of McGraw-Hill publications, with offices at Chicago, Ill., and formerly was manager of the fiber products division of the Corning Glass Works, Corning, N. Y. A biographical sketch of Mr. Morrow appeared in the February issue, page 91.

Perhaps the best approach to finding the background for the ideas of engineering educators about graduate training is to study their present operations. A glance at the catalogs of the engineering colleges, a study of the number of students and the courses they take, and an observation of the faculties and equipment devoted to graduate work leads to several conclusions as to the caliber and scope of present graduate work and its adequacy for training men to meet the present needs of industry.

The usual graduate curricula is made up of several courses in specialized engineering fields with options in other departments. Accent is placed upon technique and practice in engineering and the endeavor is to impart skill similar to that involved in practical engineering work. Because of a hobby of a professor or specialized ability, there is a tendency toward a specialization or unbalance in the graduate curricula. Often, also, experimental facilities are focused only on one major problem in research or engineering. Very few courses are given in the fundamental sciences and these are seldom taught by the best teachers in the science and engineering faculties. Examples are numerous of the endeavor to put knowledge into unco-ordinated tidbits already too prevalent in the undergraduate curricula, and to have the graduate curricula either made of assorted electives or focused upon intense specialization. With few exceptions, graduate engineering work is part of the catalog scenery and many courses are never taught. Some few schools, however, in certain branches of engineering and in a special fields, have done notable work and achieved a reputation for graduate training of a specialized character.

As a general conclusion we may say that present graduate work is without completeness or unity in plan or policy; is taught by overworked or incompetent teachers; is without adequate experimental facilities; has relatively few students enrolled; and only a few of these are qualified to do the work. We have few reasons to base plans for graduate training upon present experience and practice. There are sound reasons, however, for studying the present situation and building upon the good things found in past experience.

Objectives for Future Plans

There is no need to delve further into the market demands for graduate engineers or to make a detailed analysis of present curricula. We do not believe anyone will discuss the topic from these points of view except to point to a vastly superior development. Discussion must be based largely upon opinion and speculation about what should be done and about what can be done in the future.

As good engineers, we should start with the naming of objectives and the reasons for these objectives. We can generalize by saying that the world needs men with a more thorough training in the sciences and in the humanities so as to contribute to national well-being. We can restrict ourselves to the technical aspect and say that a man thoroughly grounded in science and engineering is needed by industry. We can point to the trend of undergraduate engineering to become a training for business and this consequently necessitates selectivity in engineering education and more time for training those who are particularly well fitted to become professional engineers. Possibly we weigh all these factors and believe graduate training for engineers is necessary for any or all of these reasons. But there are more specific service reasons for giving serious consideration to the amplification and improvement of graduate training.

If we are going to raise the standards of civilization, it must be through the use of technological levers that create more wealth and more goods and services. And it is apparent that technological advances today will not come from individual inventors or mechanics or engineers in sufficient volume or at a rate to satisfy the needs of the times. They must come through the work of well-prepared engineers and scientists who apply principles and use a technique far in advance of that used by rough-and-ready inventors or even by four-year engineering graduates.

Most industries are staffed with technical men who can carry on present activities and who can do the things that make for greater efficiency and more economy, but the big advances lie in fundamental and long-continued researches by exceedingly well-trained men. It is found frequently that two or more years of research and an expenditure of millions of dollars are involved in the development of new processes and new products in any branch of industry. It is found that an initial delving into pure science is the base for later applying engineering knowledge and methods to get commercial production.

If we can increase the number of men qualified to do this work and industry can be induced to hire them and to give them a chance to use their knowledge and ability, there is every reason to count upon their making marked advances in industrial progress and consequently raising our national standards of living.

It is the chief idea of those who advocate graduate training that men of this type and caliber are needed and can be trained and that the engineering method and approach is the best to use in their development. They apply the fundamentals of science but should be engineers in training, thought, and action.

There is a realization that the men now most active on the advance fronts of industry are the doctors in physics and chemistry. Their knowledge of science enables them to go forward from the present positions in accord with principles which bring tangible results in the shortest time and with maximum economy.

The idea of the engineering educators is to teach fundamental science by the engineering or applied method in order to turn out a better type of man to do this work than is now found available. To put it bluntly, engineering educators believe they can produce a superior product to that produced in the academic schools of science so far as the measure of competency is the ability to do the technological work now required to advance the status of industry.

It is not the thought that present graduate training as given in pure science would be duplicated, nor would it be wise for engineering educators to institute college training in specialized fields of engineering practice; their goal

should be to give a rounded and integrated course in the fundamental sciences by using the engineering or applied method of teaching. By having greater unity, a better educational method, and a more focused objective than can be found in the science departments of our universities, these educators believe that teaching science by the applied method will give a better training to the type of man needed in our technological world.

Perhaps this thought is incorrect. Possibly the pure scientists will say that the initial research work should be done by them and that the engineers should then be called upon to carry the results to commercial stages. If true, this would give an entirely different specification for graduate training in engineering.

And if we analyze the kind of problems to be solved in industry, we can get an idea of the training to give men that will aid them to get solutions. Any study of the technological aspects of industry shows that advances can be made best by men who are up-to-date in all present scientific knowledge and principles and who are sufficiently skilful to apply this knowledge in unknown areas for utilitarian purposes.

Need for Co-ordination of Knowledge

It is not enough to have training in method of attack and a knowledge of principles. There must be a finite knowledge of gases, liquids, solids, organic and inorganic materials, light, heat, sound, and electricity. There must be a supplementary knowledge of mathematics, thermodynamics, metallurgy, mechanics, hydraulics, electronics, and other subjects to motivate and focus the abstract scientific knowledge. Above all, there must be a co-ordination of knowledge and principles in order that these men may work intelligently.

The man needed by technological industry must be able to state his variables at the start of a problem, weigh their relative importance, predict their changes under changed conditions, put them together according to a planned program that is based upon a theoretical analysis and solution, and apply skill and technique to bring about a tangible answer. And, in these problems, there will be one or more variables that are impossible to evaluate by means of present knowledge; consequently, the engineer must have the ability to explore the unknown. Here again only recorded knowledge and broad principles of science are the tools available for him to use.

It may be that this specification assumes too great a scope for engineering because it is impossible to train such a man in any reasonable time. Experience seems to indicate that specialization instead of generalization is the only practicable educational procedure and that the problems of industry are best solved by the joint actions of specialists in science and engineering. But there is doubt as to the validity of this conclusion simply because the broader and better conception has not been tried. We could well discuss this alternative as it offers a relatively easy path to the goal, but it is not so logical or so theoretically effective as the endeavor to give adequate training to each individual.

This is the ideal specification for graduate training and, if the engineering colleges can fill it, rapid and major advances in technology can be counted upon to occur. This is an ambitious program to undertake; especially since the number of men that will be taken by industry in the near future at a premium wage will be limited and the cost to the colleges will be high. It is doubtful, moreover, that more than a half dozen colleges can get or now have the faculties, the facilities, and sufficient funds to give the training desired. But the opportunity to do this pioneering educational work is here and surely a few leaders will be found willing to try so that all may benefit by actual experience.

It seems practicable and best to initiate this work in some universities through the co-operation of the faculties in science and engineering. Few, if any, engineering colleges are sufficiently self-contained as to teaching staff and experimental equipment to undertake such a broad and such a thorough training as is proposed.

Since students should be selected, upon the basis of their aptitude and ability, from graduates in both science and engineering, the co-operation of the respective faculties would have other advantages. The possible sacrifice of some good elements in the engineering method of instruction would be offset by having a more competent staff and a going organization to do the work. We stress too greatly the merits of the engineering method of teaching when we deal with the more mature men and superior minds presumed to be available for graduate training, and probably a composite of academic and engineering teaching would give good results. Engineers allege that the pure scientists are academic and impractical but the scientists in turn say that the engineers are superficial and equip students only with current skills and practices. There is enough truth in both assertions to point toward a successful compromise in using a joint faculty to train the men suggested.

If the basis for graduate training is the mastery of science and mathematics, then the best men on the faculties of the schools of chemistry, mathematics, and physics should be used to give instruction. But this should be done in co-operation with the engineering faculty and the method of instruction should be modeled largely upon that used in engineering teaching in order to get a co-ordinated curricula in applied science.

A joint faculty made up of engineering and science teachers could work out the composition of a curricula with details of the courses that would permit a splendid graduate training. The first thing to do is to define the scope and objectives of the training, and in doing this the counsel of the scientific faculty and of industrial specialists is valuable and essential. The establishment of procedure and course content can be worked out next to achieve the objectives. The teaching should incorporate the engineering methods of attack and experimentation to give definiteness to the application of principles as well as to fix them so that they may be used as tools for engineering research.

The fundamental handicap to the development of graduate training is the faculty. We know that most engineering faculties are overloaded now. We know that the speci-

fications for a teacher of this kind of graduate work are so severe that few can qualify. We know that the type of teacher needed is now so eagerly sought by industry to do its work that colleges cannot meet the competition. But there are a few who like to teach and who are not tempted by salary who can form a nucleus, and, if the movement grows, it is logical to assume that much of the research work of a fundamental character now done by industry will be done in the colleges. If the colleges earn a position, undoubtedly their graduate work will be supported and they will have the teachers needed. Initially, however, the great need is for a faculty able and numerous enough to carry on both graduate and undergraduate teaching.

It will not be sufficient to take present courses in engineering, science, and mathematics and put them together to make the curricula. The result would be an artificial and unco-ordinated group of courses without unity or plan. There must be devised new courses that fit together to make an integrated whole. It will be just as difficult to reverse the present trend to put knowledge into specialized cubbyholes in engineering as it will be to do this for arts and science courses. Both planning and patience must be exercised if we wish to reach the objectives, and the curricula is the agency to do the work.

Engineers complain that mathematics is now taught in a group of artificial divisions rather than as a subject that has unity and completeness, but the same thing may be said of any curricula in engineering, with possibly the most glaring example in the present tables and groupings for teaching undergraduates in the several branches of engineering. There is need to get unity and breadth in both graduate and undergraduate curricula and to call a halt on the tendency toward a detailed separation and specialization in both science and engineering. The man most closely approximating the ideal to be sought by engineering educators is the type of scientist developed by the British educational system of a few years ago. But the depth and area of knowledge has increased so greatly since those days that some may say this type of education is impracticable for the limited time available. It would be more accurate to say that the influence of the German school of education through specialization still dominates our American universities.

If, however, we cannot train a man to have the adequate breadth and depth of knowledge in the time available, then of course we must make some measure of departmentalization in curricula. This would necessitate the use of several men in a group for attacking a single problem in industry because of the limitations of the educational system, but this is the method now prevalent in industry and is a practicable procedure. But we should first endeavor to train a rounded and not a specialized man by use of a single unified curricula. One man is always more effective than a committee to do work in this world.

Graduate engineering courses should not stress engineering practices or skills on one hand or endeavor to develop detailed specialization in pure science on the other. Nor should they require large expenditures for laboratories to be equipped with full-size engineering equipment; the laboratory work should be used to fix and illustrate principles and this requires precise measurement and first-class experimental technique rather than an experimental approach to engineering operation and practice.

The ideal man produced by this graduate training should be a master of the sciences, a master of mathematics, expert in technique, and skilled in the engineering approach to the solution of problems. He should have the ability and the enthusiasm to do new and difficult feats in industry. Such a man must devote at least four years to graduate study but his work would then be so outstanding in industry that his personal reward would be abundant and his services in constant demand.

As time goes on and the situation develops in each institution, the educational program should be to build a complete and unified faculty within the college of engineering. This would improve the graduate work and would put a needed element of breadth, depth, and quality into the present undergraduate curricula.

Even today, careful consideration should be given to incorporating the departments of science and mathematics with the college of engineering or preferably a new college of technology. There is a common ground in engineering and science not present in the hodge-podge setup now called the college of arts and sciences. Both science and engineering would benefit from a closer affiliation. There would be a more general use of a competent faculty and amplified facilities for research and experimentation. There would be more unity in policies and in educational methods. But this unity should not destroy the independence or enthusiasm of the men in pure science on one hand or eliminate the essential elements of engineering on the other. Both groups could, however, stand a little modernization and integration and would be better if administered as a unit in university organization. Departmental barriers, whether in science or in engineering, are now major handicaps to effective education.

In building graduate work there should be no tendency toward uniformity or regimentation as between colleges. The individual situations as to location, facilities, and faculty talents should be capitalized upon both as a practical procedure and as an endeavor to work out experiences and practices for the benefit of all.

Generally speaking, it would be well for the graduate faculty to be associated intimately with industry in meritorious industrial research and specialists in industry should be called upon to co-operate in the graduate training. This intimacy would work toward a mutually advantageous relationship between industry and the colleges, would create an invigorating atmosphere for the students, and would bring new and vitalizing information to the curricula. Much of the knowledge required in graduate training is not in textbooks and the method or procedure in training follows closely those used in industrial research.

It is doubtful that the usual classroom textbook method of education is at all satisfactory for use in graduate training and educators should strive to teach by use of projects and actual research problems which mostly can be supplied by industry itself.

It may be noted that technical training is stressed as

paramount in engineering graduate work at this time. There are two reasons for this. The first is that technical contributions give the best tools to improve our industrial civilization and these can be made under a practical and organized plan to train men. The other is that it is difficult, if not impossible, to give co-ordinated work that will include technical and nontechnical subjects in a limited time and under the conditions now encountered in our universities. Possibly a curricula in science, engineering, economics, sociology, history, and literature can be improvised and used, but it would be of doubtful effectiveness unless radical changes were made in university organization and procedure to knit together these courses into some degree of unity in scope and treatment. Any mere dilution of the technical curriculum with unco-ordinated electives in arts, business, or law violates the specifications for training the type of man needed and cannot be accepted as a part of an effective educational plan for the development of professional engineers.

Most of us would like to see some integrated course on the evolution of society and of industry and the relations and interrelations of technology, law, business, and sociology in their effects on civilization as a part of the education of all engineers. We would like to develop in each student a perspective on national affairs, a sound philosophy of life, and the ability to weigh his work in social terms. Possibly this can be done in time, but at present the engineering colleges can and should stress the technical aspect of graduate training. We should have faith that the utilitarian contributions of graduates to society will be assimilated and act as catalysts to cause each of us to bask in that better way of living we all desire.

A very different type of graduate training should be planned for the education of those who expect to be political, financial, or moral leaders and in this training, while necessary, the engineering faculty should be relegated to a secondary position.

We may say that the engineer by training, by experience, and by temperament is fitted to solve the social and economic problems of our civilization but this competency is not granted by others and there is no proof that the statement is true. In fact, the available evidence is against engineering as a preparation for leadership in public affairs. There is a positive danger, therefore, that this premise about the ability of the engineer may be used to set up programs for training young people to bring salvation to civilization. There are no data to warrant the establishment of such training on the premise that it would be likely to improve upon the results of the training in sociology, history, economics, law, and religion now used to develop leaders for directing national affairs. We should put this kind of a program on a trial basis, of course, but this discussion is held to the practicable and tangible opportunities in graduate training for engineers at this time. Undoubtedly some part of the curricula should also be given to training in nontechnical subjects but this is a minor consideration in this discussion. We now have the data and the knowledge to establish a system of training by use of engineering technique and scientific knowledge that will produce men who we know can contribute definite and needed things to technological progress. This should be the primary objective in graduate training.

Some day we hope the engineer will understand the thoughts of men, will sense human preoccupations and sentiments, will interpret facts to disclose truths and feelings that are deeper, and will combine desirable personal traits with his logic, his systematic attack, and his individualistic philosophy of life to be a competent leader of mankind, but I doubt the ability of the engineering colleges to train such a man through any particular curriculum, especially since the influence of character, background, and environment have such potent effects upon mental processes and human reactions.

As stated in the beginning, a discussion of graduate work must be based upon a study of present and past conditions and then projected into the future and into the realm of opinion. The outline presented here is largely a personal opinion by an incompetent observer. It is idealistic, perhaps, but it is designed to produce the desired results and to create a discussion that will no doubt differ with these conclusions.

In my opinion the answer to the proposal to institute graduate work requires a great deal of study before competent conclusions may be drawn. Such a study must cover the entire scope of engineering education and the objectives to be sought. We now have proposals that engineers should have a five- or six-year undergraduate course.

It is now agreed by educators that the present undergraduate curriculum is formed so that engineering training will be focused upon a preparation for life or for business and not for professional engineering. Some radical suggestions are made that a general course as a preparation for business be given and specialized technical courses be given to a few students who show aptitude for becoming technical engineers.

In my opinion, a study of engineering education as a whole is needed to point to the best way to give graduate training and to fix the graduate curricula. There is a possibility that a reorganization of the undergraduate curricula to permit of selectivity with respect to the few men competent to take the kind of graduate work proposed may permit of adequate postgraduate training in two years instead of four. It may even seem advisable to stop at the end of four years of undergraduate work if selectivity and technological specialization can be had in college and if industry will then co-operate in developing these men when they join commercial enterprises.

This discussion, it is hoped, will start a program of investigation rather than develop conclusions about postgraduate training. Properly sponsored investigations should be conducted by committees made up of the best men in science, engineering, and industry both within and without the ranks of the educators. We hope such a study will support the idea of graduate training of the kind proposed, but we are the first to agree that no action should be taken until facts are assembled to support opinions. Our critical times and changed conditions offer every possible inducement to engineering educators and to industry to train and to equip our young people to meet the needs of civilization to better advantage.

News

Of Institute and Related Activities

Enlarged Winter-Convention Program Results in Increased Attendance

WITH a technical program enlarged to include 17 sessions, at which 82 technical papers were presented, two general sessions, and five technical conferences, the AIEE 1939 winter convention held in New York, N. Y., January 23–27, closed with a total registered attendance of 1,610—the highest since 1924. This enlarged program, together with the careful planning and execution of the program as a whole on the part of the hard-working winter-convention committee, is believed to be largely responsible for the increased attendance. More detailed statistics on registration and attendance are given in accompanying tabulations. Included on the program were the usual entertainment features and inspection trips. A special evening program was devoted to presentation of the Edison and John Fritz medals to Past Presidents D. C. Jackson and F. B. Jewett, respectively.

Since all technical papers and related discussions ultimately will appear in the TRANSACTIONS, no reports have been published here on the technical sessions. Reports of other major events may be found on succeeding pages and elsewhere in this issue.

General Sessions

As previously announced, one of the two general sessions featured an address by the noted economist, Virgil Jordan, president of the National Industrial Conference Board, Inc.; the other was devoted to a discussion of the damages caused by the New England hurricane of September 1938 and the engineering conclusions that might be drawn from the experiences of various utility systems in the affected area. Discussions of the damages caused by the storm and of the experiences of the utilities were presented by six scheduled speakers (the essential substance of these six presentations appears elsewhere in this issue). Following the scheduled discussions, the meeting was concluded by informal discussions from the floor. H. S. Osborne, chairman of the technical program committee, presided at the hurricane session.

The other general session was opened by T. F. Barton, chairman of the winter-convention committee, who presided throughout. He first introduced Chairman-Elect C. A. Andrews of the AIEE San Francisco Section, who urged all those present to attend the combined AIEE summer and Pacific Coast convention to be held in that city June 26–30, 1939. Following Mr. Andrews' remarks, President John C. Parker spoke on "The Engineer's Social and Political Relations"; full text of his address appears elsewhere in this issue. At the conclusion of President Parker's remarks, the feature address of the session, "Enterprise and Social Progress," was delivered by Doctor Jordan; a manuscript embracing the substance of this address is expected to be made available for publication in a subsequent issue. A discussion period during which Doctor Jordan answered questions from the floor brought the session to a close.

Entertainment and Inspection Trips

As usual, the principal entertainment features of the winter-convention program consisted of the annual dinner-dance and the annual smoker. Attendance at the smoker broke the record set last year with a total of 1,264; attendance at the dinner-

Analysis of Registration at Recent Winter Conventions

District	1936	1937	1938	1939
New York City and foreign (3)	697	629	767	752
Middle Eastern (2)	222	216	292	404
North Eastern (1)	219	222	252	287
Great Lakes (5)	43	38	74	76
South West (7)	11	12	18	37
Canada (10)	11	17	14	28
Southern (4)	15	21	11	16
Pacific (8)	4	7	5	4
North West (9)	3	1	3	2
North Central (6)	6	2	2	4
Totals	1,231	1,165	1,438	1,610

Attendance at Special Features of Recent Winter Conventions

Feature	1937	1938	1939
Total registration	1,165	1,438	1,610
Smoker	1,175	1,201	1,264
Dinner-dance	500*	651	527
Inspection trips	926	1,012	1,167

* Estimated.

Analysis of Registration at 1939 Winter Convention

Classification	Dist. 3	Dist. 1	Dist. 2	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	660	251	345	13	63	3	36	3	1	23	2	1,400
Men guests	42	20	34		10	1	1	1	1	3	1	114
Women guests	47	16	25	3	3					2		96
Totals	749	287	404	16	76	4	37	4	2	28	3	1,610

Attendance at Sessions and Conferences

Time		Attendance
Technical Sessions		
Monday		
10:00 a.m.	Relays	200
10:00 a.m.	Selected subjects	100
2:00 p.m.	Protective devices	215
2:00 p.m.	Transportation	175
2:00 p.m.	Electronics and industrial power applications	85
Tuesday		
9:30 a.m.	Symposium on rating of electrical machinery and apparatus—I	210
9:30 a.m.	Communication—I	90
9:30 a.m.	Switching transients	175
2:00 p.m.	Symposium on rating of electrical machinery and apparatus—II	150
2:00 p.m.	Communication—II	200
2:00 p.m.	Power generation	240
Wednesday		
2:00 p.m.	Symposium on rating of electrical machinery and apparatus—III	175
2:00 p.m.	Power transmission and distribution	210
2:00 p.m.	Electric welding	85
Thursday		
9:30 a.m.	Cables	185
9:30 a.m.	Basic sciences	35
9:30 a.m.	Instruments and measurements	125
Technical Conferences		
Monday		
10:00 a.m.	Sound	125
4:00 p.m.	Electronics	*
Tuesday		
2:00 p.m.	Definitions	*
Wednesday		
2:00 p.m.	Network analysis and synthesis	*
Thursday		
9:30 a.m.	Teaching of communication engineering and electronics	100
General Sessions		
Wednesday		
10:00 a.m.	Enterprise and Social Progress	275
Thursday		
2:00 p.m.	Experiences from the New England hurricane	381

* Not reported.

dance totaled 527. As usual, there was a special program of entertainment events for the women guests.

Inspection trips to a variety of local points of interest rounded out the "extra curricular" portion of the program. As in recent previous years, the last scheduled day of the convention was devoted entirely to inspection trips; there were also trips on other days of the convention. Attendance statistics are given in accompanying tabulations.

Directors and Committees Meet

In accordance with the usual custom, the AIEE board of directors met during convention week. The national nominating committee also met, in accordance with the Institute's bylaws, to select nominees for election to Institute offices for the year 1939–40. Reports of both these meetings are given in succeeding pages.

Meetings of the following Institute committees also were held during winter-convention week: automatic stations; basic sciences; communication; electric welding; electrochemistry and electrometallurgy; instruments and measurements; Lamme medal; lightning arrester subcommittee; membership; planning and co-ordination; power generation; power transmission and distribution; protective devices; research; safety; Sections; technical program; transformer subcommittee; and transportation. Following the custom established several years ago, the committee on Student Branches held a luncheon for Branch counselors attending the convention, which was followed by informal discussions. Brief reports of some of these meetings are given in succeeding pages.

Registration for Inspection Trips

Trip	Registration
Sponsored broadcast, General Electric Company, NBC Studios	50
Columbia University cyclotron	57
Fluorescent-lighted railroad car and portable battery-charging rectifier—New York Central Railroad Company	50*
Sponsored broadcast, Consolidated Edison Company of New York, Inc., NBC Studios	46
Jacob Ruppert's brewery	35
Electric ferry and fireboat—City of New York	35
Automatic substation—Interborough Rapid Transit Company	31
Lamp works, elevator factory, and meter works—Westinghouse Electric and Manufacturing Company, Bloomfield, Jersey City, and Newark, N. J.	102
Essex generating station, Public Service Electric and Gas Company, Newark, N. J.	19
Electrical Testing Laboratories, New York, N. Y.	57
New York Stock Exchange	47
Western Electric Company cable and apparatus plant, Kearny, N. J.	89
Sponsored broadcast, Cities Service Company, NBC Studios	100
Newspaper plant, *Daily News*, New York	59
Trip to World's Fair	40
Museum of Science and Industry Television tour, Radio City Observation roof, Radio City Broadcast tour, Radio City	250*
Hayden Planetarium	100*
Total	1,167

* Approximate.

Winter-Convention Committee

The committee responsible for the success of this year's convention consisted of: T. F. Barton, *chairman;* G. E. Dean, E. E. Dorting, F. M. Farmer, L. C. Miller, H. S. Osborne, J. H. Pilkington, A. L. Powell, C. S. Purnell, George Sutherland, and W. W. Truran. Committees in charge of special events were as follows:

Dinner-Dance. T. S. Bacon, *chairman;* K. F. Bellows, Tomlinson Fort, S. B. Graham, F. G. Guldi, J. L. Holton, Thomas Maxwell, S. A. Smith, Jr., P. W. Spence, and F. Van Olinda.

Smoker. D. W. Taylor, *chairman;* A. J. Cooper, P. G. Fredericks, William Jordan, J. E. McCormack, J. H. Moore, E. G. D. Paterson, T. D. Reimers, W. H. Rogers, B. J. Rowan, M. L. Waring, E. E. Wolff, and W. R. Van Steenburgh.

Inspection Trips. R. F. Brower, *chairman;* C. L. Chatham, C. F. Fowler, R. M. Kime, H. G. Life, L. A. Nelson, R. R. Peatfield, and Henry Vidal.

Women's Entertainment. Mrs. A. F. Dixon, *chairman;* Mrs. T. S. Bacon, Mrs. T. F. Barton, Mrs. C. R. Beardsley, Mrs. R. F. Brower, Mrs. H. C. Dean, Mrs. F. M. Farmer, Mrs. Tomlinson Fort, Mrs. A. H. Kehoe, Mrs. H. S. Osborne, Mrs. A. L. Powell, Mrs. G. S. Rose, Mrs. W. R. Smith, Mrs. George Sutherland, Mrs. D. W. Taylor, and Mrs. H. R. Woodrow.

Sections Committee Met During Winter Convention

Among the various AIEE committees that held meetings during the Institute's recent winter convention was the Sections committee. Through the efforts of H. H. Race and M. S. Coover, respectively chairman and secretary of that committee, this brief report of the meeting has been made available.

Actions taken by the Section committee since its meeting in Washington, D. C., on June 20, 1938, were first summarized. Among these actions were:

1. Extension of territory of Muscle Shoals Section to include Marshall and Madison Counties in Alabama.

2. Extension of territory of San Francisco Section to include six counties in Nevada (Washoe, Ormsby, Storey, Lyon, Douglas, and Mineral).

3. Formation of an AIEE San Diego (Calif.) Section (report of organization meeting appears elsewhere in this issue).

AIEE President John C. Parker spoke briefly on Section activities. He called attention to the need of "some better method for determining the identity of students graduating and entering the profession in order to hold them in touch with the Institute." He mentioned also the difficulty that the young men in the Institute find in making acquaintance with the older men. It was reported that some Sections solve this problem by appointing younger members on each of the Section committees, thus drawing them into contact with the older members and inducting them into Institute activity. All Sections were urged to use this method as far as may be practical.

Concerning members residing in territory not now assigned to any Section, the general policy was endorsed that wherever practicable the members in such territories should receive notices from and be made to feel a part of the Section nearest to them. In large areas such as the states of South Carolina and West Virginia, Sections should be formed as early as there is sufficient local interest and justification. In smaller areas such as groups of counties in Maine, New Hampshire, Vermont, and Pennsylvania, the chairman of the Sections committee was empowered to consult with the vice-president and Section officers concerned to allocate to the nearest Section such auxiliary territory.

Chairman Race presented a chart summarizing the information received on Section activities, in response to his letter of December 27, 1938, which was addressed to all Section chairmen. The object of this effort is to inform all Sections on the projects that have proved most interesting and helpful. The suggestion was made that the Sections committee undertake the preparation of a pamphlet summarizing these numerous and diverse activities so as to make available to incoming Section officers a background of experience of all Sections.

Chairman W. C. Kalb of the Cleveland Section reported that a division of that Section had been formed at Mansfield, Ohio, under the leadership of C. A. Faust (announced in the January issue). He reported also that the interest and number of members are such that plans now are under way for formation of a Mansfield Section.

A report on the status of the licensing of professional engineers was presented by C. R. Beardsley, chairman of the Institute's special committee on model registration law. He said that the National Council of State Boards of Engineering Examiners had invited the Institute to co-operate in the formulation of examinations for candidates for license; also that the AIEE board of directors had authorized funds for the printing and distribution to Section officers of copies of the latest revision of the model law. W. H. Timbie, former chairman of the Sections committee, was appointed to represent the Sections committee in this project.

Student Branch Committee Met During Convention

An open meeting to discuss matters related to AIEE Student Branches was held during the Institute's recent winter convention in New York, N. Y. This brief report of the proceedings was made available by Chairman R. W. Sorensen of the Student Branches committee.

Although attended by only three committee members, the total attendance was 52, representing 36 engineering colleges and several industries that have training courses for college graduates. The geographic regions were practically all represented, as was nearly every type of engineering college. Many of those present took active part in discussing the several questions up for consideration, and numerous valuable suggestions were contributed.

By practically unanimous action the assembled group voted to recommend the following program:

1. The booklet "The Electrical Engineer" should be issued as soon as possible, and a committee of

three should be appointed to carry out this instruction.

2. Henceforth Student Branches shall be authorized only at colleges whose electrical-engineering curricula are accredited by Engineers' Council for Professional Development, but no retroactive action shall be taken regarding Branches established before the accrediting plan was put into operation.

3. Recommended that a change be made in method of grading student papers from the one now in operation to the one recommended by AIEE District number 1, which has been set forth in E. M. Strong's letter of February 7.

4. Recommended that the proposed Chas. F. Scott memorial celebration be promoted for the Branches next year. Chairman Sorensen was authorized to appoint a committee of three to investigate the possibility of having Doctor Scott prepare a talking record for distribution to Student Branches to be used during the year.

5. There was much discussion about ways for presenting activities of the Institute to students, the best suggestion being that made by A. C. Stevens: that Institute vice-presidents be urged to give more attention to visiting Branches. This seemed particularly pertinent because inquiry brought forth the statement that very few vice-presidents had consistently made Branch visits, although occasionally some vice-president in several of the various Districts during his term of office did make it his business to visit the Branches in his region.

With the meeting open for other suggestions, the following were presented:

1. That consideration be given as to what to do about inactive Branches.

2. That Branches be invited to make nominations through counselors and officers for candidates for Eta Kappa Nu awards.

3. That student sessions be carried on more frequently in conjunction with national conventions.

4. That the noon open Student Branch committee luncheon be made continuing in connection with the winter convention.

The committee appointed to reissue the booklet "The Electrical Engineer" is composed of the chairman of the Student Branches committee, National Secretary H. H. Henline, and H. H. Race.

AIEE Committee on Safety Reports Recent Activities

By action of the AIEE board of directors during the year 1937–38, the functions of the Institute's committee on safety codes were expanded and the committee on safety created to include the entire field of safety in electrical engineering. This report of the current progress of that committee has been prepared by W. C. Wagner, committee secretary.

The committee in letters has endeavored to interest universities, and in particular their electrical-engineering departments, in the matter of accident prevention and including instruction in the proper method of resuscitation from electric shock, asphyxiation, and drowning. Suggestions have been included that other departments of the universities may also be interested in the subject, with emphasis on instruction to all students, particularly because of the frequent occurrence of such accidents outside of university laboratories. Such training among the electric and gas utility companies has resulted in the saving of the lives of many persons who have accidentally come in contact with energized parts, or have apparently drowned, or asphyxiated from gas fumes. The committee is convinced that continual training in this method is absolutely essential and that, to be most effective, such training should be given before students leave the universities. Letters were therefore sent to 120 professors of electrical engineering of the various universities and colleges, together with a booklet describing the Schafer prone pressure method of resuscitation. The replies were immediate and evidenced a highly cooperative spirit. Correspondence is continuing with such universities.

Letters were also sent by the committee to the counselors of AIEE Student Branches of the universities, requesting that during the year each Student Branch arrange to have presented before the Branch a paper dealing with some phase of the problem of prevention of accidents or remedial measures after electrical shock. This had been discussed with the chairman of the committee on Student Branches and received his whole-hearted endorsement. Assistance was offered if necessary, to secure a local speaker to prepare and present such a paper. Again the reaction was spontaneous, and steps have been initiated to attain this during this or the coming year, where this subject had not already been included in the meetings.

A similar letter was authorized to be sent to the various Sections of the Institute, recommending that during each year a paper be presented before each Section dealing with the prevention of accidents or remedial measures after electrical shock. It was found that, in general, arrangements were being made by the Sections to include this important subject in their programs.

There exists a great need for the distribution of a comprehensive booklet on resuscitation of convenient size, which people could readily obtain for reference.

A movement has been started to obtain information relating to safety practices from all related foreign institutes of various kinds. Abstracts are being prepared of replies received, and it is hoped that a comprehensive summary of practices will shortly be available.

The committee was successful early in the year in arranging for the preparation of a paper for the general meeting. The paper now under preparation is concerned with safe practices in college laboratories, dealing largely with methods to assure safety to the laboratory students and personnel.

During the year a number of subjects relating to electrical safety were presented for discussion. It was found that such subjects being given active consideration were concerned with the developments in, or revision of, electrical codes or standards in general sponsored under the auspices of the American Standards Association. Some of the subjects, from a purely technical viewpoint, are being given further consideration.

Reports of Two Conferences Held During AIEE Winter Convention

AS REPORTED elsewhere in this issue, five technical conferences were included on the program of the AIEE 1939 winter convention held recently in New York, N. Y.; these were on the following subjects: sound; electronics; definitions; network analysis and synthesis; and teaching of communication engineering and electronics. Brief reports of the conferences on definitions and network analysis and synthesis have been made available by the respective conference chairmen.

Conference on Definitions

By Michel G. Malti, Chairman

The third of a series of technical conferences on definitions was held during the winter convention on Tuesday, January 24, at 2:00 p.m. Prepared discussions were presented by A. Boyajian (A'18, F'26) of the General Electric Company, H. L. Hazen (A'26) of the Massachusetts Institute of Technology, W. A. Lewis, Jr. (A'27) of the Westinghouse Electric and Manufacturing Company (now of Cornell University), S. A. Schelkunoff (M'34) of the Bell Telephone Laboratories, B. R. Teare (A'29, M'36) of Yale University, and J. D. Tebo (A'36, M'36) of the Bell Telephone Laboratories.

After each written discussion the meeting was open for general comments which came from many of those present revealing enthusiasm that is hard to surpass. The object of this series of conferences is to supply subcommittee 1 of committee 42, operating under the procedure of the American Standards Association, with a set of suggestions which will help it in drafting improved definitions of fundamental terms. Definitions of engineering terms are important. Correct and consistent definitions are of more than scientific and academic interest. The membership is therefore invited to participate actively in these conferences.

Network Analysis and Synthesis

By Edward L. Bowles, Chairman

A fourth annual informal conference on network analysis and synthesis was held during the winter convention on the following subjects:

THE APPLICATION OF THE TENSOR CONCEPT TO THE COMPLETE ANALYSIS OF LUMPED ACTIVE NETWORKS, with applications of the solution to single and multiple video-amplifier stages. Presentation by D. W. Epstein and H. L. Donley, RCA Manufacturing Company.

AN EXPERIMENTAL NETWORK WITH SEVERE PHASE REQUIREMENTS. Presentation by E. B. Payne (A'20), Bell Telephone Laboratories.

A DISCUSSION OF THE INDEPENDENT VARIABLES CHARACTERIZING NETWORK BEHAVIOR AND THE ALTERNATIVE SETS OF VARIABLES WHICH MAY BE USED. Presentation by E. A. Guillemin (A'24), Massachusetts Institute of Technology.

The interest of those attending, as evidenced both by informal expression of

opinion and by lively pointed discussion and informal exchanges of ideas, is an ample testimonial to the service these meetings are effecting.

In the chairman's opinion the potentialities of informal technical conferences of this nature have not yet been fully realized. It is his sincere hope that these meetings where men may meet as man to man informally to exchange ideas without the inhibitions of formality and recorded publication will be continued.

Edison and Fritz Medals Presented During Winter Convention

FORMAL presentation of the 1938 Edison Medal of the AIEE and of the 1939 John Fritz Medal transpired at a special session of the recent AIEE winter convention held Wednesday evening, January 25, 1939. The Edison Medal, highest award of the AIEE, was presented to Doctor Dugald C. Jackson, a past president of the Institute, "for outstanding and inspiring leadership in engineering education and in the field of generation and distribution of electric power." The John Fritz Medal, highest American engineering honor, was presented to Doctor Frank B. Jewett, also a past president of the Institute, "for vision and leadership in science, and for notable achievement in the furtherance of industrial research and development in communication." President John C. Parker presided over the Edison Medal ceremonies, and Past President W. H. Harrison, vice-chairman of the John Fritz Medal board of award, presided over the Fritz Medal ceremonies.

History of Edison Medal Sketched by National Secretary Henline.

President Parker first introduced National Secretary H. H. Henline who briefly outlined the history of the Edison Medal as follows: "About 35 years ago the Edison Medal Association was formed by associates and friends of Thomas A. Edison, who desired to develop a suitable method for recounting and celebrating the achievements of a quarter of a century in the art of electric lighting, with which Mr. Edison had been prominently identified.

"The Association reached a decision that the most effective means of accomplishing its objective was by the establishment of a gold medal which could serve as an honorable incentive to scientists, engineers, and artisans to maintain by their work the high standards of accomplishment which had been set by Mr. Edison.

"The American Institute of Electrical Engineers accepted an invitation to undertake the responsibility of making the awards. The Edison Medal committee, which is charged with this responsibility, is composed of 24 members. Three are appointed each year by the president for a term of five years each; three are elected each year by the board of directors from its own membership for a term of two years. The president, the national treasurer, and the national secretary are ex-officio members of the committee.

"The bylaws of the committee provide for making an annual award of the medal, and the deed of gift states that it shall be made to someone resident in the United States or Canada, for meritorious achievement in electrical science, electrical engineering, or the electrical arts.

"The medal, which was designed by James Earle Fraser, carries on its obverse a portrait of Thomas A. Edison, and on its reverse

The Roster of John Fritz Medalists

1905 Lord Kelvin (HM'92). For his work in cable telegraphy and other scientific achievements.

1906 George Westinghouse (A'02). For the invention and development of the air brake.

1907 Alexander Graham Bell (A'84, M'84, past president). For the invention and introduction of the telephone.

1908 Thomas Alva Edison (A'84, M'84, HM'28). For the invention of the duplex and quadruplex telegraph, the phonograph, the development of a commercially practical incandescent lamp, the development of a complete system of electric lighting, including dynamos, regulating devices, underground system, protective devices, and meters.

1909 Charles T. Porter. For his work in advancing the knowledge of steam engineering and in improvements in engine construction.

1910 Alfred Noble. For notable achievements as a civil engineer.

1911 Sir William H. White. For notable achievements in naval architecture.

1912 Robert W. Hunt. For his contributions to the early development of the Bessemer process.

1913 No award.

1914 John E. Sweet. For his achievements in machine design and pioneer work in applying sound engineering principles to the construction and development of the high-speed steam engine.

1915 James Douglas. For notable achievement in mining, metallurgy, education, and industrial welfare.

1916 Elihu Thomson (A'84, M'91, F'13, HM'28, past president). For achievement in electrical invention, in electrical engineering and industrial development, and in scientific research.

1917 Henry M. Howe. For his investigations in metallurgy, especially in the metallography of iron and steel.

1918 J. Waldo Smith. For achievement as engineer in providing the City of New York with a supply of water.

1919 George W. Goethals. For achievement as builder of the Panama Canal.

1920 Orville Wright. For achievement in the development of the airplane.

1921 Sir Robert A. Hadfield. For the invention of manganese steel.

1922 Charles Prosper Eugene Schneider. For achievement in metallurgy of iron and steel, for the development of modern ordnance, and for notable patriotic contribution to the winning of the great war.

1923 Guglielmo Marconi (HM'17). For the invention of wireless telegraphy.

1924 Ambrose Swasey (HM'28). For achievement as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, a benefactor of education, and the founder of Engineering Foundation.

1925 John Frank Stevens. For great achievements as a civil engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern and Siberian Railways.

1926 Edward Dean Adams (A'10). For great achievements as engineer, financier, scientist, whose vision, courage, and industry made possible the birth at Niagara Falls of hydroelectric power.

1927 Elmer Ambrose Sperry (A'84, M'93). For the development of the gyro-compass and the application of the gyroscope to the stabilization of ships and airplanes.

1928 John Joseph Carty (A'90, M'03, F'13, HM'29, past president). For pioneer achievement in telephone engineering and in the development of scientific research in the telephone art.

1929 Herbert Hoover (HM'29). As engineer, scholar, organizer of relief to war-stricken peoples, public servant.

1930 Ralph Modjeski. For notable achievement as an engineer of great bridges combining the principles of strength and beauty.

1931 David Watson Taylor. For outstanding achievement in marine architecture, for revolutionary results of persistent research in hull design, for improvement in many types of warships and for distinguished service as chief constructor of the United States Navy during the World War.

1932 Michael Idvorsky Pupin (A'90, F'15, HM'28, past president). Scientist, engineer, author, inventor of the tuning of oscillating circuits and the loading of telephone circuits by inductance coils.

1933 Daniel Cowan Jackling. For notable industrial achievement in initiating mass production of copper from low-grade ores, through application of engineering principles.

1934 John Ripley Freeman. Engineer—preeminent in the fields of hydraulics and water supply, fire insurance economics, and analysis of earthquake effects.

1935 Frank Julian Sprague (A'87, M'97, F'12, HM'32, past president). For distinguished service as inventor and engineer through the application and control of electric power in transportation systems.

1936 William Frederick Durand. As authority in hydrodynamic and aerodynamic science and in its practical application; outstanding leader in research and in engineering education.

1937 Arthur Newell Talbot. Moulder of men, eminent consultant on engineering projects, leader of research, and outstanding educator in civil engineering.

1938 Paul Dyer Merica. For important contributions to the development of alloys for industrial purposes.

1939 Frank Baldwin Jewett (A'03, M'10, F'12, past president). For vision and leadership in science, and for notable achievement in the furtherance of industrial research and development in communication.

Future AIEE Meetings

South West District Meeting
Houston, Texas, April 17–19, 1939

North Eastern District Meeting
Springfield, Mass., May 3–5, 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Great Lakes District Meeting
Minneapolis, Minn., September 27–29, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Winter Convention
New York, N.Y., January 22–26, 1940

an allegorical conception of the genius of electricity, crowned by fame."

Jackson Qualifications Epitomized by J. W. Barker

Following Mr. Henline's remarks, President Parker introduced J. W. Barker, dean of engineering of Columbia University, New York, N. Y., one of the many prominent men who had obtained his engineering training under Doctor Jackson. Dean Barker referred to "a more formal Edison Medal address" that he had prepared for publication in Electrical Engineering (full text appeared in the February issue, pages 64–6). He then proceeded to relate various anecdotes to show "something of what those men who have lived and worked with the Medalist. . . feel has come into their lives from him," tying these into the outline of the more formal published presentation.

Speaking of the closeness of contact between Doctor Jackson and his students, Dean Barker cited the series of teas for students at the Jackson home, initiated during the early part of the Medalist's educational career and continued throughout. He called particular attention to Doctor Jackson's educational philosophies, one of the most important of which is that the students "should be thrown into contact with the unknown as early as possible and gotten away from the cut-and-dried presentations of the textbook."

Doctor Jackson's Response

At the conclusion of Dean Barker's address, President Parker presented the medal and certificate to Doctor Jackson. Expressing his deep appreciation of the honor, Doctor Jackson called attention to the fact that never before has an Edison Medal citation coupled engineering education with engineering practice. "Indeed the phrase engineering education," he continued, "never before has been used in such a citation. The use here seems to me significant of the present relation in the field of electrical engineering, where education and practice are now recognized as complementary parts of one whole; and it turns me to the theme of engineering education, to the exclusion (at this time) of directly discussing the science and art of electric-power practice which is the conjoined part of this citation."

The major part of Doctor Jackson's address was devoted to a discussion of some of the early history of electrical-engineering education, in which field he pioneered, relating some of his experiences as the first head of the electrical-engineering department at the University of Wisconsin and his later experiences at the Massachusetts Institute of Technology. The essential substance of his address is scheduled for publication in an early issue.

History of Fritz Medal Outlined by W. H. Harrison

Immediately following the Edison Medal ceremonies, President Parker turned the meeting over to Past-President W. H. Harrison, vice-chairman of the John Fritz Medal board of award, who spoke as follows on the history of the medal:

"The name of John Fritz is so familiar to all engineers that I need make only passing mention of the deeds that make him still live to those of us in the profession. His name and achievements are a legend wherever iron and steel men relive the early days in the development of that great industry in the Lehigh Valley.

"Striking as were his achievements as an engineer, impressive as was his influence in molding the foundations of our industrial world, his greatness as a man overshadows these accomplishments. As a matter of fact it is as a man and as a unique per-

The Roster of Edison Medalists

1909 Elihu Thomson (A'84, M'91, F'13, HM'28, past president). For meritorious achievement in electrical science, engineering, and arts, as exemplified in his contributions thereto during the past 30 years.

1910 Frank J. Sprague (A'24, M'97, F'12, HM'32, past president). For meritorious achievement in electrical science, engineering, and arts, as exemplified in his contributions thereto.

1911 George Westinghouse (A'02). For meritorious achievement in connection with the development of the alternating-current system for light and power.

1912 William Stanley (A'87, M'98, F'13). For meritorious achievement in invention and development of alternating-current systems and apparatus.

1913 Charles F. Brush (A'84, M'84, HM'29). For meritorious achievement in the invention and development of the series arc lighting system.

1914 Alexander Graham Bell (A'84, M'84, past president). For meritorious achievement in the invention of the telephone.

1916 Nikola Tesla (A'88, F'17). For meritorious achievement in his early original work in polyphase and high-frequency electrical currents.

1917 John J. Carty (A'90, M'03, F'13, HM'29, past president). For his work in the science and art of telephone engineering.

1918 Benjamin G. Lamme (A'03, M'03). For invention and development of electrical machinery.

1919 W. L. R. Emmet (A'93, M'94, HM'33). For inventions and developments of electrical apparatus and prime movers.

1920 Michael I. Pupin (A'90, F'15, HM'28, past president). For his work in mathematical physics and its application to the electrical transmission of intelligence.

1921 Cummings C. Chesney (A'94, M'99, F'13, HM'38, past president). For early developments in alternating-current transmission.

1922 Robert Andrews Millikan (M'22, HM'33). For his experimental work in electrical science.

1923 John W. Lieb (A'87, M'92, F'13, past president). For the development and operation of electric central stations for illumination and power.

1924 John W. Howell (A'87, M'88, F'12). For his contributions toward the development of the incandescent lamp.

1925 Harris J. Ryan (A'87, M'95, F'23, past president). For his contributions to the science and the art of high-tension transmission of power.

1927 William D. Coolidge (A'10, M'34). For his contributions to the incandescent electric-lighting and the X-ray arts.

1928 Frank B. Jewett (A'03, M'10, F'12, past president). For his contributions to the art of electrical communication.

1929 Charles F. Scott (A'92, M'93, F'25, HM'29, past president). For his contributions to the science and art of polyphase transmission of electrical energy.

1930 Frank Conrad (M'23). For his contributions to radio broadcasting and short-wave radio transmission.

1931 E. W. Rice, Jr. (A'87, M'88, F'13, HM'33, past president). For his contributions to the development of electrical systems and apparatus and his encouragement of scientific research in industry.

1932 Bancroft Gherardi (A'95, M'04, F'12, past president). For his contributions to the art of telephone engineering and the development of electrical communication.

1933 Arthur E. Kennelly (A'88, M'99, F'13, HM'33, past president). For meritorious achievements in electrical science, electrical engineering, and the electrical arts as exemplified by his contributions to the theory of electrical transmission and to the development of international electrical standards.

1934 Willis R. Whitney (A'01). For his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research.

1935 Lewis B. Stillwell (A'92, M'92, F'12, past president). For distinguished engineering achievements and his pioneer work in the generation, distribution, and utilization of electric energy.

1936 Alex Dow (A'93, M'95, F'13, HM'37). For outstanding leadership in the development of the central station industry and its service to the public.

1937 Gano Dunn (A'91, M'94, F'12, past president). For distinguished contributions in extending the science and art of electrical engineering, in the administration of great engineering works, and for inspiring leadership in the profession.

1938 Dugald C. Jackson (A'87, M'90, F'12, past president). For outstanding and inspiring leadership in engineering education and in the field of generation and distribution of electric power.

sonality that he gives us our greatest inspiration.

"In these perplexing times his life's work is refreshing, for it reads like the history of America itself. There are two passages which I should like to quote from a biographical sketch written in the early part of this century:

> John Fritz was born August 21, 1822, in Londonderry, Chester County, Pa. His grandfather, Johannes Fritzius, of Hesse Cassel, settled in Pennsylvania in 1802. His father, George Fritz, married the daughter of a Scotch-Irish immigrant. They had seven children—four girls and three boys—of whom John was the first.
>
> His father, a millwright and mechanic, repeatedly followed the call of the trade which he loved better than farming; and the three sons, inheriting his talent and his predilection, after dutifully following the plough in their youth, abandoned it for the pursuit of mechanical engineering, in which, educating themselves without the aid of technical instruction, they all achieved high position.

"Thus he started his life with the most modest background. As to his work, continuing the quotation:

> During nearly 30 years of work with Bethlehem Iron Company, Mr. Fritz, supported by the faith and courage which he inspired in other men, made that enterprise one of the most famous in the world. The introduction of open-hearth furnaces and of the Thomas basic process; the progressive improvements of strength, simplicity, and automatic handling in the rolling-mills; the adoption of the Whitworth forging-press; the manufacture of armorplate; the erection of a 125-ton steam hammer; and innumerable other improvements in the manufacture of iron and steel, owe their present perfection in a large degree to his inventive genius, practical resourcefulness, and patient study.
>
> The stamp of his mind may be found on almost every detail of construction and operation throughout a wide range of processes and products.

"It was that background that impelled his associates and friends to establish the John Fritz Medal 37 years ago, and it is that same background that moves us to revere his memory tonight.

"As to the medal, the idea was conceived in connection with the planning of the celebration of his 80th birthday on August 21, 1902, and the first award was appropriately made to him at that time.

"The Rules of Award provide that: 'The medal shall be awarded for notable scientific or industrial achievement.' 'There shall be no restriction on account of nationality or sex,' and that 'awards shall be made (annually) by a board of 16, appointed or chosen in equal numbers from the membership of the four national engineering societies: civil, mining, mechanical, and electrical.'

"The roster of John Fritz Medalists contains the names of 34 of the world's most illustrious engineers and scientists, among whom are those immortals in our own field of electricity: Kelvin, Bell, Edison, Elihu Thomson, Westinghouse, Marconi, and Pupin. Mention of these names gives more eloquent expression to the deep significance of this award than anything further I can say."

High Lights of Jewett Career Presented by Doctor Compton

Doctor Harrison concluded his remarks by introducing Doctor Karl T. Compton (F'31) president of the Massachusetts Institute of Technology, Cambridge, who outlined the principal achievements of Medalist Jewett. Full text of Doctor Compton's address appears elsewhere in this issue.

Doctor Jewett's Response

At the conclusion of Doctor Compton's address, Doctor Harrison presented the medal and certificate to Doctor Jewett who, in accepting the medal, said "I find myself in a whirlpool of conflicting emotions."

"On the one hand," Doctor Jewett continued, "is a sense of humility which verges on a fear that I am an impostor accepting for myself something, the major part of which belongs to others—my associates, present and past. This is not a new feeling nor is this public confession of it the first I have made. I have been the recipient of many honors, and at other times and in other places when they have come to me I have acknowledged my debt to my associates. The feeling was never stronger than it is on this occasion because the honor is the greatest I have ever received from my fellow scientists and engineers.

"In the mood of this feeling of humility I can only say that no one knows better than I do the degree to which success in modern engineering is the result of cooperative effort and one in which the dice of individual credit are frequently loaded somewhat by chance. If it were physically possible and could be done without offense to those who have made the award, I think I would cut this medal up into many parts, each one a tiny replica of the original and distribute them to a host of associates, each separate replica wrapped up in a particular personal expression of my appreciation for assistance given.

"Naturally most of them would go to members of the Bell System family, but there would be an amazing number outside and some of them would appear in surprising places. . . . The biggest replica, however, one cut from the very center of the Medal, would be a birthday present to the other partner in the family firm—my wife—without whose love, support, and wise advice, I would have fallen short in many things.

"And now for a look at the other side of the vortex of my emotions. Here I find nothing but elation. Not just the elation of receiving a new and valuable bauble or the plaudits of the crowd but the elation which comes only from knowing that you have been judged by your clan and approved. Every one likes to receive tokens of esteem and plaudits even when one knows that the crowd is fickle and may be showering anathema the next instant. There is another sort of commendation however. It is the kind the ancient philosopher had in mind when centuries ago he made the wise observation, the exact words of which I am sorry to say I have forgotten, to the effect that the only worth-while judgments are those of men who are themselves worthy of favorable judgment. When, therefore, the tribes of the clan through representatives whom they consider worthy pass judgment on a clansman, it justifies elation of a different and more substantial sort."

In the remaining major part of his address, Doctor Jewett presented "a few fragments of his history and philosophy." The essential substance of this portion of his address is scheduled for publication in an early issue.

Nominating Committee Announces Candidates

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1939, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, N. Y., January 23, 1939. This committee, in accordance with the constitution and bylaws, consists of 15 members, one selected by the executive committee of each of the ten geographical Districts, and five selected by the board of directors from its own membership.

The following members of the committee were present: C. A. Andrews, San Francisco, Calif.; C. R. Beardsley, New York, N. Y.; F. M. Farmer (for a part of the meeting), New York, N. Y.; E. S. Fields, Cincinnati, Ohio; O. C. Haycock, Salt Lake City, Utah; T. G. LeClair, Chicago, Ill.; A. H. Lovell, Ann Arbor, Mich.; F. R. Maxwell, Jr., University, Ala.; L. N. McClellan, Denver, Colo.; M. J. McHenry, Toronto, Ont.; C. A. Powel, East Pittsburgh, Pa.; A. L. Powell, New York, N. Y.; R. W. Sorensen, Pasadena, Calif.; A. C. Stevens, Schenectady, N. Y.; J. B. Thomas, Fort Worth, Tex.; A. M. MacCutcheon (alternate), Cleveland, Ohio; and H. H. Henline, New York, N. Y., secretary of the committee.

The following is the list of official candidates selected by the committee:

For President

F. Malcolm Farmer, vice-president and chief engineer, Electrical Testing Laboratories, New York, N. Y.

For Vice-Presidents

C. T. Sinclair, electrical engineer, transmission and distribution, Duquesne Light Company, Pittsburgh, Pa. (Middle Eastern District, number 2).

E. E. George, superintendent of system operation, Tennessee Electric Power Company, Chattanooga (Southern District, number 4).

Albert L. Turner, chief engineer, Northwestern Bell Telephone Company, Omaha, Neb. (North Central District, number 6).

H. W. Hitchcock, chief engineer, Southern California Telephone Company, Los Angeles (Pacific District, number 8).

J. M. Thomson, chief designing engineer, Ferranti Electric, Ltd., Toronto, Ont., Canada (Canadian District, number 10).

For Directors

Mark Eldredge, chief engineer, Memphis Power and Light Company, Memphis, Tenn.

R. E. Hellmund, chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Frank J. Meyer, vice-president in charge of operation, Oklahoma Gas and Electric Company, Oklahoma City.

For National Treasurer

W. I. Slichter, professor of electrical engineering and head of department, Columbia University, New York, N. Y.

The constitution and bylaws of the Institute provide that the nominations made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and bylaws:

Constitution

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the National Secretary when and as provided in the By-laws; such petitions for the nomination of

Vice-Presidents shall be signed only by members within the District concerned.

BY-LAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the National Nominating Committee not later than March twenty-fifth of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the National Nominating Committee in accordance with Article VI of the Constitution and sent by the National Secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(Signed) National Nominating Committee
by H. H. Henline, *Secretary*

BIOGRAPHICAL SKETCHES OF NOMINEES

In order that those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been nominated, brief biographical sketches are given in the "Personals" columns of this issue.

South West District Meeting in Houston, April 17–19

THE AIEE South West District meeting will be held in Houston, Tex., April 17–19, 1939. Headquarters for the meeting will be in the Rice Hotel. The program is complete with technical sessions on varied subjects of particular interest to the Southwest, three student sessions, and attractive entertainment features.

Houston offers unusual opportunities to visitors interested in engineering and industry. It is 50 miles inland from the Gulf of Mexico, yet is the nation's third largest seaport. On both sides of the ship channel are many industries and vast oil refineries. Nearby is the San Jacinto Battleground. Fifty miles to the south are the beaches of the Gulf of Mexico at the island city of Galveston with its new causeway connecting it to the mainland. Houston is virtually surrounded by oil and gas wells which may be seen in any degree of completion from any of the highways entering the city. One thousand oil companies have offices in Houston. Within 50 miles are the Gulf Coast sulphur mines where most of the world's supply of natural sulphur is obtained.

TECHNICAL SESSIONS

The technical program presents a variety of papers on such subjects as electrical equipment for oil-field tool manufacturing, power plants, voltage regulators, carrier telephone systems, relays, electrical aspects of petroleum prospecting, design of capacitor-type bushings, short-circuit forces in bus structures, substations, symmetrical components, signaling, phase-angle control, and symposia on pipe line corrosion and operating experience with rural lines. Approximately a dozen papers will be presented in the various student sessions.

INSPECTION TRIPS

Three major inspection trips are scheduled. Arrangements may be made at the registration desk for trips to any industry or other place of interest not scheduled. Guides and maps will be available to assist drivers in reaching the various points on the trips.

1. *Deepwater Power-Champion Paper Trip.* These two plants are on the ship channel about 11 miles from convention headquarters. The Houston Lighting and Power Company plant is of 147,000-kw capacity and has a 1,400-pounds-pressure turbine. The Champion Paper and Fibre Company manufactures paper from slash pine. Transportation at nominal cost will be provided for those not using their own cars.

2. *Telephone Company—Underground Network—Office Building Air Conditioning Systems Trip.* This trip includes inspection of local and toll offices of Southwestern Bell Telephone Company, the underground networks of Houston Lighting and Power Company, and air-conditioning apparatus in large office buildings. It is in the business district of the city and no transportation is required.

3. *Turning Basin—San Jacinto Battleground—Radio Station Trip.* A launch will be available at the Turning Basin for a short trip on the ship channel. At San Jacinto Battleground is a magnificent new monument. Near San Jacinto are radio stations KPRC and KTRH simultaneously using a 375-foot vertical self-supporting radiator. The battleground is about 18 miles from convention headquarters. Transportation will be provided at nominal cost for those requiring it.

ENTERTAINMENT AND SPORTS

No definite program of sports is being planned. Arrangements for play at several clubs may be made with the committee. The entertainment committee has planned a real Dutch stag supper at low cost for Monday night, the 17th. Tuesday noon a joint luncheon with the Houston Engineers' Club will be held in the Rice Hotel. Tuesday at 7:30 a dinner dance will be given in the Rice Hotel ballroom.

WOMEN'S ENTERTAINMENT

The following program is planned for women attending the convention:

Monday, 1:30 to 8:30 p.m. Sightseeing trip and informal supper at the Carolina Pines.

Tuesday, 10 a.m. to 2:30 p.m. Bridge luncheon at the Braeburn Country Club.

Tuesday, 7:30 p.m. Dinner dance, Rice Hotel.

Transportation will be provided for the visiting women by women of the Houston Section. Complete details of entertainment will be available at the registration desk.

ADVANCE REGISTRATION

Members in the nearby territory who will attend the meeting are urged to register in advance by returning the advance-registration card which they will receive by mail. This will be helpful to committees and will permit badges to be made ready in advance, thus avoiding congestion at the registration desk.

HOTEL RESERVATION

All members planning to attend should make their own hotel reservations early by writing direct to the hotel. All the hotels listed elsewhere are within a few minutes

Principal Hotels in Houston and Rates

Hotel	Single Room With Bath	Double With Bath	
		Double Bed	Twin Beds
Rice*	$2.50 to $6.00	$4.00 to $7.00	$6.00 to $8.00
Ben Milam	2.50 to 5.00	3.50 to 4.00	4.50 to 5.00
Lamar	2.00 to 6.00	4.00 to 6.00	5.00 to 8.00
Sam Houston	2.00 to 3.00	3.00 to 4.00	4.00 to 5.00
Texas State	3.00 to 5.00	4.50 to 5.00	5.00 to 8.00
William Penn	2.00 to 3.00	3.00 to 4.00	4.00 to 5.00

* Meeting headquarters.

Texas Company photo

Seismographic prospecting is one of the various subjects to be discussed at the forthcoming AIEE South West District meeting. Measurements are recorded by oscillographs installed on motor trucks, such as the one shown above

Tentative Program

Monday, April 17

8:00–10:00 a.m.—Registration

10:00 a.m.—General Meeting

Announcements, F. C. Bolton, vice-president, AIEE South West District.

Address of welcome, H. O. Clarke, Jr., vice-president, Houston Lighting and Power Company.

10:30 a.m.—Technical Session

Presiding: E. A. Heath, Kansas Gas and Electric Company, and C. F. Terrell, Gulf States Utilities Company.

Electricity in an Oil Field Equipment Manufacturing Plant, **Seth Evans,** Hughes Tool Company.

The Mountain Creek Plant, **H. K. Doyle,** Dallas Power and Light Company.

Resonant-Type Constant-Current Regulators, **R. R. Miner,** Kansas Gas and Electric Company.

1:30 p.m.—Inspection Trips

6:30–8:30 p.m.—Stag supper, Gulf Brewing Company

Tuesday, April 18

9:00–10:30 a.m.—Technical Session

Presiding: H. P. Lawther, Southwestern Bell Telephone Company, and J. W. Ramsay, University of Texas.

Line Problems Relating to the Type J Open-Wire Carrier System, **L. M. Ilgenfritz, R. N. Hunter,** and **A. L. Whitman,** Bell Telephone Laboratories.

Some Applications of the Type J Carrier System, **L. C. Starbird** and **J. D. Mathis,** Southwestern Bell Telephone Company.

9:00 a.m.–12:05 p.m.—Student Session

Presiding: J. M. Wilson, Rice Institute, and J. V. Bowman, Southern Methodist University.

Papers from Student Branches of Rice Institute, University of Missouri, Missouri School of Mines and Metallurgy, University of Texas, and University of New Mexico.

10:45 a.m.–12:05 p.m.—Technical Session

Presiding: Louis P. Thein, St. Mary's University and Marvin Thrasher, Texas Power and Light Company.

Carrier Current Relaying, **E. H. Bancker,** General Electric Company.

Out of Step Blocking and Selective Tripping With Impedance Relays, **H. R. Vaughan,** Westinghouse Electric and Manufacturing Company, and **E. C. Sawyer,** Gulf States Utilities Company.

12:15 p.m.—Luncheon meeting with Houston Engineers' Club, Rice Hotel

1:30–3:15 p.m.—Technical Session

Presiding: P. H. Robinson, Houston Lighting and Power Company, and B. F. Meador.

Geophysical Prospecting, **L. W. Blau,** Humble Oil and Refining Company.

Electrical Equipment in Reflection Seismograph Prospecting, **C. C. Nash** and **C. C. Palmer,** Humble Oil and Refining Company.

3:30–5:15 p.m.—Technical Session

Symposium: Electricity in Pipe Line Corrosion. Leader: J. C. Stirling, Stanolind Pipe Line Company, Tulsa. Contributors: R. A. Brannon, Humble Pipe Line Company, Houston; V. L. Nealy, Texas Pipe Line Company, Houston; W. H. Stewart, Sun Oil Company, Beaumont; David Harrell, Jr., Houston Pipe Line Company, Houston; and Earl Lipscomb, Western Union Telegraph Company, Dallas.

7:30 p.m.—Dinner Dance

Wednesday, April 19

9:00–10:30 a.m.—Technical Session

Presiding: A. L. Jones, Jr., General Electric Company, and V. O. Clements, Westinghouse Electric and Manufacturing Company.

Improvements in the Construction of Condenser Bushings, **A. J. A. Peterson,** Westinghouse Electric and Manufacturing Company.

An Electro Mechanical Analysis of Short Circuit Forces in Simple Bus Structures, **E. W. Boehne,** General Electric Company.

A Survey of Contemporary Practice in the Application of Factory-Built Substations, **Frank M. Starr,** General Electric Company.

9:00 a.m.–12:15 p.m.—Student Session

Presiding: W. C. Morris, Agricultural and Mechanical College of Texas, and A. J. McCrocklin, University of Texas.

Papers from Student Branches of Oklahoma Agricultural and Mechanical College, Kansas State College, Texas Technological College, University of Oklahoma, and Southern Methodist University.

10:45 a.m.–12:15 p.m.—Technical Session

Presiding: J. S. Porter, Westinghouse Electric and Manufacturing Company.

Mutual Inductance, Impedance, Power, and Symmetrical Components Expressed in Terms of Matrices, **Myril B. Reed,** Armour Institute of Technology.

Signalling Over Zero Sequence Network, **J. D. Browder,** Oklahoma Gas and Electric Company.

12:15 p.m.—Luncheon conference, counselors and Branch chairmen

1:30–3:15 p.m.—Technical Session

Presiding: L. E. Cook, Texas Power and Light Company, and H. M. Stewart, Humble Oil and Refining Company.

Recent Developments in Generator Voltage Regulation, **C. R. Hanna, K. A. Oplinger,** and **C. E. Valentine,** Westinghouse Electric and Manufacturing Company.

Combined Voltage and Phase Angle Control Under Load, **H. L. Reynolds,** Allis-Chalmers Manufacturing Company.

1:30–4:30 p.m.—Student Session

Presiding: John Burt, Texas Technological College, and J. Jacobson, University of New Mexico.

Papers from Student Branches of University of Arkansas, University of Kansas, Washington University, and Agricultural and Mechanical College of Texas.

3:45–5:00 p.m.—Technical Session

Symposium: Operating Experiences of Utilities With Rural Lines. Leader: Bryce Brady, Oklahoma Gas and Electric Company, Enid. Contributors: P. H. Underwood, Houston Lighting and Power Company, Houston; G. W. Bean, Texas Electric Service Company, Fort Worth; N. B. Gussett, San Antonio Public Service Company, San Antonio; R. R. Miner, Kansas Gas and Electric Company, Wichita; C. M. Lytle, Kansas City Power and Light Company, Kansas City; L. E. Cook, Texas Power and Light Company, Dallas; and E. B. Jennings, Southwestern Bell Telephone Company, Dallas.

walk of the Rice, the headquarters hotel, and are largely or entirely air conditioned.

Student Branch Convention

The Branches at Rice Institute and the Agricultural and Mechanical College of Texas will act as hosts. Three student sessions have been provided and it is expected each Branch will present a paper. The Tuesday afternoon session should be of particular interest to students as the speakers will bring valuable information about the relatively new field of electricity in geophysics and petroleum prospecting. All trips and entertainment features of the convention are open to students. Additional inspection trips may be arranged. Branch counselors should contact the counselor at Rice Institute for information on trips to oil fields, sulphur mines, or other points of interest. Hotel facilities for students are available at $1.25 per person. Counselors should make reservation direct with the hotel for their student group.

Committees

Committees for the meeting are as follows:

General meeting: F. C. Bolton, L. T. Blaisdell, V. O. Clements, Seth Evans, and H. C. Dillingham.

Entertainment: H. P. Heafer, chairman.

Attendance and publicity: J. B. Arthur, chairman.

Transportation and inspection: L. K. Del Homme, chairman.

Hotels and registration: H. F. Staacke, chairman.

Finance: B. M. Wise, chairman.

Meetings and papers: N. F. Rode, chairman.

Student activities: N. F. Rode, chairman of counselors; J. S. Waters, R. P. Ward.

Plans Near Completion for North Eastern District Meeting

Plans for the AIEE North Eastern District meeting to be held at the Hotel Kimball, Springfield, Mass., May 3–5, 1939, are now approaching the final stages.

Four technical sessions, one general session, and one or two student sessions will be scheduled. Technical sessions are to be on industrial power application, power generation, power transmission and distribution, and selected subjects. The session on power generation will feature a symposium on hydrogen-cooled turbogenerators. The general session will present a guest speaker of national prominence, who will speak on phases of economics which are of national importance and interest. The program for the student session is to be arranged by E. M. Strong of Cornell University.

Inspection Trips

Inspection trips of varied interest have been arranged to several of the diverse industrial plants of Springfield and nearby cities during the meeting period. Included are:

Bigelow Sanford Carpet Company, Thompsonville Conn.

Stevens Paper Company, Westfield, Mass.
Morart Rotophoto Company, Holyoke, Mass.
Fisk Rubber Company, Chicopee, Mass.
Chapman Valve Manufacturing Company, Indian Orchard, Mass.
Westinghouse Electric and Manufacturing Company, East Springfield, Mass.
Package Machinery Company, Springfield, Mass.
Springfield Armory, Springfield, Mass.

A trip after the meeting is being arranged for Saturday morning, May 6, to the Pratt and Whitney Aircraft Corporation, Hartford, Conn.

Members desiring to attend the inspection trip to either the Pratt and Whitney Aircraft Corporation or the Springfield Armory, may be required to submit proof of citizenship. Ladies will not be admitted at either of these two places. The trip to the Springfield Armory is expected to be very popular.

Originally established by the Massachusetts Bay Colony as a supply depot during the Revolutionary War, the present site of the Springfield Armory was visited and selected by George Washington for a federal armory in 1789. Congress passed an act establishing it as such in 1794. The first Springfield musket was produced in 1795. Since that time the Springfield Armory has done practically all the development and normally a very large part of the production of the shoulder arms of the armed forces of the United States, and for years the Springfield rifle has had the reputation of being the finest small arm of its class in the world.

The armory has an interesting museum of war relics and small arms of all descriptions from many countries, ancient and modern. This complete collection covers the evolution of the shoulder arm from the ancient Chinese hand cannon to the modern Garand rifle, the latest development of the Springfield Armory. At the museum the Blanchard lathe, built in 1822, may be seen. Although originally designed for turning gun stocks, which it did at the rate of two per hour, it had a great influence on the boot and shoe industry in New England.

Arrangements have been made for the entertainment of members and their guests, but details have not yet been released by the committee.

AIEE Section Organized at San Diego

The AIEE San Diego Section, authorized by the AIEE board of directors in December 1938, held its organization meeting in San Diego, Calif., January 18, 1939. Seventeen members and two guests attended this first meeting of the Institute's 66th Section, whose territory consists of San Diego and Imperial counties.

Officers were elected to take office immediately and serve until August 1, 1939. They are: F. F. Evenson (A'21, M'29) consulting engineer, San Diego, *chairman;* W. L. Bryant (A'28, M'37) electrical engineer, Imperial Irrigation District, Imperial, *vice-chairman;* C. J. Nevitt (A'33) electrical estimator, San Diego Consolidated Gas and Electric Company, San Diego, *secretary-treasurer;* and H. A. Campbell (A'35) electrical engineer, Consolidated Aircraft Corporation, San Diego, R. P. Thompson (A'25) engineer, Southern California Telephone Company, San Diego, D. W. Proebstel (A'18, M'21) electrical engineer, Imperial Irrigation District, Imperial, and E. E. Eiler (M'24) La Jolla, *executive committee.* L. M. Klauber (A'11, F'23) vice-president in charge of operation, San Diego Consolidated Gas and Electric Company, presided at the meeting.

AIEE Directors Meet During Winter Convention

THE regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on January 24, 1939.

Present were: *President*—John C. Parker, New York, N. Y. *Past Presidents*—W. H. Harrison, New York, N. Y.; A. M. MacCutcheon, Cleveland, Ohio. *Vice-Presidents*—F. C. Bolton, College Station, Tex.; C. L. Dawes, Cambridge, Mass.; F. M. Farmer, New York, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. N. McClellan, Denver, Colo.; M. J. McHenry, Toronto, Ont.; I. Melville Stein, Philadelphia, Pa.; and Edwin D. Wood, Louisville, Ky. *Directors*—C. R. Beardsley, C. R. Jones, H. S. Osborne, New York, N. Y.; F. Ellis Johnson, Madison, Wis.; W. B. Kouwenhoven, Baltimore, Md.; F. H. Lane, L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; C. A. Powel, East Pittsburgh, Pa.; D. C. Prince, Philadelphia, Pa.; and R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation for a part of the meeting were Doctors William McClellan, president, and F. M. Feiker, executive secretary of American Engineering Council, Washington, D. C.

Regrets were presented from Director Vannevar Bush, of Washington, D. C., absent on account of illness, and Vice-President J. P. Jollyman of the Pacific District.

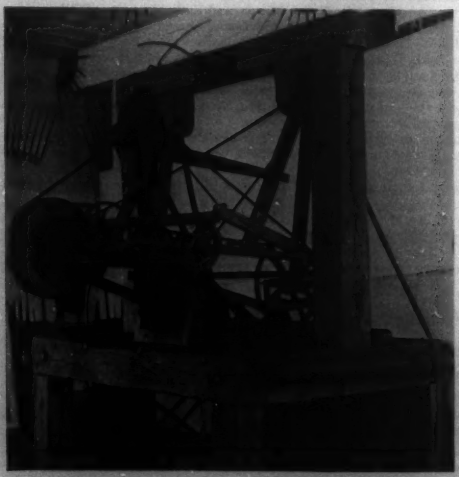
Minutes were approved of meetings of the board of directors on October 25, 1938, and the executive committee on December 16, 1938.

Disbursements for January, amounting to $23,776.04, were reported by Chairman Jones of the finance committee and approved by the board.

As the Institute's budget which was adopted last October included an appropriation for American Engineering Council for only the period of six months beginning October 1, 1938, consideration was given to the question of a further contribution; and the board voted an additional appropriation of $3,000 for the current budget year, ending September 30, 1939, without any commitment as to future contributions.

A report was presented and approved of a meeting of the board of examiners held January 19, 1939. Upon the recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 8 applicants were transferred and 11 were elected to the grade of Member; 90 were elected to the grade of Associate; 144 Students were enrolled.

A resolution was adopted "that the 1939 annual meeting of the American Institute



Blanchard lathe, constructed in 1822 for turning gun stocks, at Springfield Armory

Future Meetings of Other Societies

American Chemical Society. Annual spring meeting, April 3–7, 1939, Baltimore, Md.

American Electrochemical Society. Spring convention, April 26–29, 1939, Columbus, Ohio.

American Institute of Chemical Engineers. 31st semiannual meeting, May 15–17, 1939, Akron, Ohio.

American Institute of Mining and Metallurgical Engineers. 22d national open hearth convention, April 26–28, 1939, Cleveland, Ohio.

American Physical Society. 227th meeting, April 27–29, 1939, Washington, D. C.

American Railway Engineering Association. Annual convention, March 14–16, 1939, Chicago, Ill.

American Society for Testing Materials. 42d annual meeting, June 26–30, 1939, Atlantic City, N. J.

American Society of Civil Engineers. Spring meeting, April 19–22, 1939, Chattanooga, Tenn.

American Society of Mechanical Engineers. Semiannual meeting, July 10–14, 1939, San Francisco, Calif.

American Society of Refrigerating Engineers. Spring meeting, May 21–22, 1939, Hershey, Pa.

Association of Iron and Steel Engineers. Annual spring conference, March 27–28, 1939, Birmingham, Ala.

Edison Electric Institute. Annual sales conference, March 20–24, 1939, Chicago, Ill.
Technical committees meeting, May 1–4, 1939, Chicago, Ill.

Institute of Radio Engineers. Joint meeting with American section of the International Scientific Radio Union, April 28–29, 1939, Washington, D. C.

National Electrical Manufacturers Association. May 14–18, 1939, Hot Springs, Va.

National Fire Protection Association. Annual meeting, May 8–12, 1939, Chicago, Ill.

Society for the Promotion of Engineering Education. 47th annual meeting, June 19–23, 1939, State College, Pa.

Society of Automotive Engineers. SAE world automotive engineering congress, May 22, 1939.

of Electrical Engineers be held in San Francisco, California, on Monday, June 26." A schedule of national conventions and District meetings, recommended by the committee on planning and co-ordination, was adopted, as follows: winter convention, New York, January 22–26, 1940; summer convention, Swampscott, Mass., June 24–28, 1940; Pacific Coast convention, Vancouver, B. C., dates to be decided later; and a Middle Eastern District meeting, Cincinnati, Ohio, in the fall.

Section 93 of the bylaws was amended to read as follows:

Sec. 93. The manuscript of any paper to be presented at a national meeting or convention of the Institute must be received at Institute headquarters for the consideration of the technical program committee not less than 60 days before the date of presentation. With a view to setting up a schedule for the orderly conduct of the work, the technical program committee may specify such additional periods as may be necessary. The executive committee shall have the power to waive the 60-day requirement upon request of the chairman of the technical program committee.

No paper shall be announced for presentation at any national meeting or convention until after the paper has been accepted for presentation by the technical program committee.

Upon recommendation of the publication committee, based upon the results of an inquiry addressed to the membership to ascertain the demand for the book, the board authorized the publication of a 17-year cumulative index to the TRANSACTIONS, which will be sold at $2 per copy.

The board approved in principle proposed revisions of sections 45, 46, 47, and 98 of the bylaws, relating to the publication and release of papers presented at Section, Branch, and District meetings. The revisions will therefore take the usual course for formal adoption by the board of directors at a later meeting.

Upon the recommendation of the committee on research, the board voted to apply to The Engineering Foundation for continued support, during the year beginning October 1, 1939, of a research project at Johns Hopkins University on stability of impregnated paper insulation; also to accept technical sponsorship of a research project on insulating oils and cable saturants at Massachusetts Institute of Technology and to request The Engineering Foundation to accept financial sponsorship of the project.

Doctor Vannevar Bush and Doctor H. S. Osborne were reappointed representatives of the Institute on the council of the American Association for the Advancement of Science for the year 1939.

F. Malcolm Farmer was nominated for re-election by the United Engineering Trustees, Inc., as a member of The Engineering Foundation board for the four-year term beginning in October 1939.

Gano Dunn was reappointed an Institute representative on the Hoover Medal board of award for the six-year term beginning in May 1939.

The board confirmed the appointment by the president of the following delegates of the Institute to the 1939 transportation symposium under the auspices of The Franklin Institute, at Philadelphia, Pa., on February 7, 1939: C. M. Davis, J. V. B. Duer, W. S. H. Hamilton, F. B. Powers, I. Melville Stein, and Sidney Withington.

The president was empowered to appoint a delegate to attend the centennial celebration of Duke University, at Durham, N. C., April 21–23, 1939, and a delegate to the Engineering Congress to be held at Wellington, N. Z., in February 1940, during the centenary of the official founding of New Zealand.

The board expressed its sympathy for transmittal to the members of the family of Charles S. Ruffner, who died on January 21, 1939. Mr. Ruffner was a manager of the Institute 1916–20, and vice-president 1920–21.

Other subjects were discussed, reference to which may be found elsewhere in this issue or in future issues of ELECTRICAL ENGINEERING.

Honor Memory of Elihu Thomson

A meeting in commemoration of the life and work of Professor Elihu Thomson, who at the time of his death nearly two years ago was recognized as the dean of American scientists, was held in the halls of the American Philosophical Society and the Franklin Institute in Philadelphia, Pa., on February 16, 1939. Papers, each dealing with a different phase of his life, were read by nine men high in the scientific and electrical art, who were closely associated with Professor Thomson during his lifetime.

Although Professor Thomson is credited with more than 700 inventions and was one of the founders of the General Electric Company, he always shunned publicity and as a result little has been written on his life and work. No biography exists today, despite the fact he received honors greater than any other American scientist during his lifetime. The papers presented in Philadelphia form the nucleus of a biography, and in addition, several other former associates of Professor Thomson have prepared manuscripts dealing with some important phase of his life or work, which are now on file in the library of the American Philosophical Society.

Speakers at the meeting were Vannevar Bush (A'15, F'24), W. D. Coolidge (A'10, M'34), D. C. Jackson (A'87, F'12), A. G. Davis (A'98, F'12), H. T. Stetson, A. L. Rohrer (A'87, M'88), J. L. Haney, R. S. Morris, and K. T. Compton (F'31).

Following presentation of the papers, a talking motion picture in which Professor Thomson is interviewed on some of his more important accomplishments by the late E. Wilbur Rice, Jr., former president of the General Electric Company, was shown.

The old Central High School in Philadelphia, which Professor Thomson attended as a boy and at which he later became an instructor in chemistry and mechanics, is still standing and was open to inspection. Professor Thomson gave up his teaching

New-Member Activity

New members are needed both to supply our natural losses and to maintain Institute progress. Have you assisted in bringing in a new member this year?

National Membership Committee

at this school in 1880 to join the newly formed American Electric Company in New Britain, Conn., the forerunner of the Thomson-Houston Electric Company, later consolidated with Thomas A. Edison's company in Schenectady to form the present General Electric Company. He died March 13, 1937. A charter member of the AIEE, he became its fifth president in 1889, and was elected to honorary membership in 1928.

American Engineering Council

Fact-Finding Inquiries

The patent inquiry now underway with funds provided by the National Industrial Conference Board, and under the direction of the AEC patents committee, directs attention to one of the primary opportunities for united action of engineers on public questions. A seven-page summary of these several fact-finding projects of the American Engineering Council is available on request.

American Engineering Council considers its opinions on public affairs are best expressed by the collection and interpretation and distribution of factual information. A brief list of these inquiries follows:

Twelve Hour Shift in American Industry. Published in book form by E. P. Dutton Company from monies supplied by the Cabot Fund. Price—$2.50

Waste in Industry. Published in book form by McGraw-Hill Book Company from monies furnished by the Russell Sage Foundation and individual contributions. Price—$2.50

Business Cycles and Unemployment. Published in book form by McGraw-Hill Book Company with funds provided by individual contributions. Price—$2.50

Industrial Coal—Purchase, Delivery and Storage. Published in book form by Ronald Press Company with funds secured from interested groups. Price—$2.50

Civil Aviation. Published in book form by McGraw-Hill Book Company with funds provided by Howard Coffin in co-operation with the Department of Commerce. Price—$2.50

Safety and Production. Published in book form by Harper and Brothers with funds contributed by National Bureau of Casualty and Surety Underwriters. Price—$2.50

Street Traffic Signs, Signals and Markings. Published in pamphlet form by American Engineering Council with funds from American Automobile Association, National Automobile Chamber of Commerce, and several street-railway companies. Price—$0.25

Recent Economic Changes. Published in co-operation with committee on recent economic changes by McGraw-Hill Book Company in two volumes. Three chapters on agriculture, technical changes in manufacturing industries, and changes in old and new industries, were prepared from funds supplied by the committee on recent economic changes. Price—$2.50 each

Airport Drainage and Surfacing. Published in pamphlet form by the Department of Commerce.

Survey of the Engineering Profession. Available in part in a series of pamphlets reprinted from the *Monthly Labor Review*, prepared by the Bureau of Labor Statistics with the co-operation of the member societies of American Engineering Council. (Articles reporting phases of this survey were published in ELECTRICAL ENGINEERING as follows: "Professional Aspects of Engineering Education," August 1936, pages 863–7; "Unemployment in the Engineering Profession," February 1937, pages 216–23; "Employment in the Engineering Profession," May 1937, pages 524–31; "Security of Engineering Employment," June 1937, pages 655–61; "Engineering Income and Earnings," September 1937, pages 1089–1104; "Sources of Engineering Income, 1929–34," November 1937, pages 1353–58; and "Monthly Earnings of Engineers, 1929–34," December 1937, pages 1450–60.)

Patent Inquiry. Now underway with funds provided by the National Association of Manufacturers and the National Industrial Conference Board to be published about January 1940.

In all these studies, Council approaches the problem from the viewpoint of the professional engineer, namely, first to assemble the facts; second, to analyze and coordinate them; and third, to recommend principles made evident by these facts. In the capital goods industries, construction industries, the extractive and public utilities industries, the engineer is professionally related both in fields of management and the field of technology. He brings to the consideration of public problems involving labor and capital and management practices and methods, the viewpoint of a professional man. In this viewpoint he seeks to express opinion based on facts, nonpartisan, nonpolitical, with the public good as the major objective. AEC seeks to maintain in all these undertakings a reputation for fairness and sound judgment, coupled with a practical understanding of the workings of industry and trade.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and the other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Skew Factor for Coils in Skewed Slots

To the Editor:

It has been my experience to find that the derivation of the skew factor for coils which lie in skewed slots has been omitted from the more popular texts on a-c machinery. The analysis which leads to the determination of this factor is given below. A more general and comprehensive treatment of winding factors can be found in L. V. Bewley's paper "Induced Voltage of Electrical Machines" which appeared in the AIEE TRANSACTIONS for April 1930.

Referring to figure 1, the total flux linked by the skewed coil of one turn is

$$\phi = \sum_{M=1}^{\infty} \int_{-\frac{L}{2}}^{\frac{L}{2}} \int_{y \tan \theta}^{y \tan \theta + \tau} B_n \sin\left(\frac{n\pi x}{\tau}\right) dx dy \quad (1)$$

where

L = active length of conductor
y = axial distance along the core
θ = mechanical angle of skew
τ = pole pitch distance
B_n = maximum flux density of nth harmonic
x = peripheral distance
λ = electrical angle of skew

$$\phi = \sum_{M=1}^{\infty} \int_{-\frac{L}{2}}^{\frac{L}{2}} \left| B_n \frac{\tau}{M\pi} \cos\left(\frac{M\pi x}{\tau}\right) \right|_{y \tan \theta}^{y \tan \theta + \tau} dy \quad (2)$$

$$\phi = \sum_{M=1}^{\infty} - B_n \frac{\tau}{M\pi} \int_{-\frac{L}{2}}^{\frac{L}{2}} - \left\{ \cos \frac{M\pi}{\tau} (y \tan \theta + \tau) - \cos\left(\frac{M\pi}{\tau} y \tan \theta\right) \right\} dy \quad (3)$$

$$\phi = \sum_{M=1}^{\infty} B_n \frac{2\tau}{M\pi} \int_{-\frac{L}{2}}^{\frac{L}{2}} \times \cos\left(\frac{M\pi}{\tau} y \tan \theta\right) dy \quad (4)$$

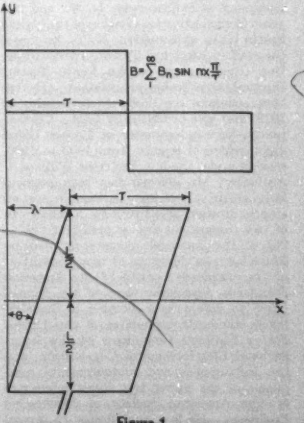


Figure 1

This follows from the fact that the space distribution of flux, normally does not contain even harmonics so that $\cos n\pi = -1$.

$$\phi = \sum_{M=1}^{\infty} \frac{2}{\tan\theta} B_n \left(\frac{\tau}{M\pi}\right)^2 \times \Big|_{-\frac{L}{2}}^{\frac{L}{2}} \sin\left(\frac{M\pi}{\tau} y \tan\theta\right) \quad (5)$$

$$\phi = \sum_{M=1}^{\infty} \frac{4}{\tan\theta} B_n \left(\frac{\tau}{M\pi}\right)^2 \times \sin\left(\frac{M\pi L}{2\tau} \tan\theta\right) \quad (6)$$

where

$$\tan\theta = \frac{\lambda \times \tau/\pi}{L}$$

$$\phi = \sum_{M=1}^{\infty} 4 \times \frac{L}{\lambda \times \tau/\pi} B_n \left(\frac{\tau}{M\pi}\right)^2 \times \sin\left[\frac{M\pi L}{2\tau} \lambda \frac{\tau}{\pi} \frac{1}{L}\right] \quad (7)$$

$$\phi = \sum_{M=1}^{\infty} \left(2LB_n \frac{\tau}{n\pi}\right) \frac{\sin n\lambda/2}{n\lambda/2} \quad (8)$$

If $\lambda = 0$, then

$$\frac{\sin n\lambda/2}{n\lambda/2} = 1$$

so that the flux linked by the coil for zero skew is

$$\phi_{\lambda=0} = \sum_{M=1}^{\infty} 2LB_n \tau/n\pi \quad (9)$$

From which it follows that the skew factor for the nth harmonic is

$$K_s = \frac{\sin n\lambda/2}{n\lambda/2}$$

Thus skewing the slots $\lambda = 2\pi/n$ electrical degrees will eliminate the nth harmonic.

Very truly yours,
D. L. JAFFE (A'35)
(Marcellus Hartley Laboratory, Columbia University, New York, N. Y.)

Personal Items

F. M. Farmer Nominated for Presidency

Frank Malcolm Farmer (A'02, M'12, F'13) vice-president and chief engineer of Electrical Testing Laboratories, New York, N. Y., has been nominated for the presidency of the AIEE for the 1939–40 term. Born at Ilion, N. Y., March 28, 1877, Mr. Farmer was graduated from Cornell University with the degree of mechanical engineer in 1899. In 1903, after $1^1/_2$ years in the test department of the General Electric Company at Schenectady, N. Y., and $2^1/_2$ years in the inspection division of the United States Navy at Brooklyn, N. Y., he joined the staff of Electrical Testing Laboratories, Inc. (then known as the Lamp Testing Bureau) as a technical assistant. He became engineer in 1906, chief engineer in 1912, and vice-president in 1929. Concurrently, he was instructor at Cooper Union night school of science from 1902 to 1906, serving under the late Professor William A. Anthony. Mr. Farmer has been particularly active at various periods in several standardization organizations: as chairman of two committees and as president (1924–25) of the American Society for Testing Materials; as chairman of two committees of the standards council of the American Standards Association and of the council (1936 to date); as a member of the electrical standards committee of the United States National Committee of the International Electrotechnical Commission, and the instruments and measurements committee of the power test codes committee of The American Society of Mechanical Engineers. He is a contributor to several reference books, and author of a book on electrical measurements and of many papers given before engineeering and technical societies. His Institute paper on "The Performance of High Tension Cables" in 1926 received both the national best paper prize and the regional best paper prize. He is at present a member of the board of United Engineering Trustees, Inc., and of the Engineering Societies monographs committee, and chairman of The Engineering Foundation, on all of which bodies he represents the Institute. He has served on the following Institute committees: standards, 1919–22, 1923 to date; power transmission and distribution 1920–1938; electric welding, 1927–28, 1930–31; research, 1929–1938 (chairman, 1933–36); technical program, 1933–36, 1938 to date; award of Institute prizes, 1933–36; executive, 1934–36, 1937 to date; and Edison Medal, 1934–38. In addition, Mr. Farmer has been a member of the Institute's board of examiners, 1923–28, 1936–38; chairman of the headquarters committee, 1936–38; and member of the Institute policy committee, 1937–38. He was a director from 1934 to 1938 and at present is serving as vice-president representing the New York City District (number 3). He is also a member of the finance committee and of the committee on transfers and is chairman of the committee on planning and co-ordination. In addition to his Institute activities, Mr. Farmer is a director of the American Standards Association; a past president of the American Society for Testing Materials; a past president of the American Welding Society; a fellow of the American Association for the Advancement of Science; a member of the Institution of Electrical Engineers (Great Britain) and of The American Society of Mechanical Engineers.

F. M. FARMER

Vice-Presidential Nominees Are Sinclair, George, Turner, Hitchcock, and Thomson

Carroll Taylor Sinclair (A'19, M'29, F'36) electrical engineer in the transmission and distribution division of Duquesne Light Company, Pittsburgh, Pa., has been nominated to serve the Institute as vice-president representing the Middle Eastern District (number 2). Born December 16, 1894, at Towson, Md., Mr. Sinclair was graduated from Baltimore Polytechnic Institute in 1913 and received a degree in electrical engineering from Lehigh University in 1917. That year he became an engineering assistant with the Western Union Telegraph Company, New York, N. Y., but later entered the United States Army. After his discharge as a second lieutenant of the engineers' corps, he became assistant testing engineer with the Pennsylvania Water and Power Company, Holtwood, in 1919. In 1922 he became assistant to the superintendent of stations, but he left later that year to join the United Electric Light and Power Company, New York, in the chief planning division. In 1923 he became superintendent of transmission and distribution. In 1925 he went to Pittsburgh as assistant electrical engineer in the transmission and distribution division of the Duquesne Light Company. In 1927 he was made electrical engineer for the Byllesby Engineering and Management Corporation, the name of which company, in Pittsburgh, became the Duquesne Light Company in the 1936 reorganization. Mr. Sinclair has written extensively, particularly on the subjects of transmission and distribution. He has also lectured at various universities and technical schools. He was editor-in-chief of the underground systems reference book published by the National Electric Light Association in 1931 and has been very active in that organization (now Edison Electric Institute). He is a member of the American Society of Civil Engineers. He has served the Institute as a member of the committees on power transmission and distribution, 1929–39 (chairman 1935–37); technical program, 1935–37; and standards, 1936–39, and was chairman of the Pittsburgh Section, 1930–31.

C. T. SINCLAIR

E. E. GEORGE

A. L. TURNER

H. W. HITCHCOCK

J. M. THOMSON

Everett Elwood George (A'20, M'29, F'36) superintendent of system operation, The Tennessee Electric Power Company, Chattanooga, has been nominated to serve the Institute as vice-president representing the Southern District (number 4). Born November 27, 1892, at Madison, Ind., Mr. George was graduated from Purdue University with a bachelor of science degree in 1913. His early employment was with the following companies: American Rotary Valve Company, Anderson, Ind. (test foreman, 1913); Barney and Smith Car Company, Dayton, Ohio (assistant efficiency engineer, 1914); National Steel Car Company, Hamilton County, Ohio (production engineer, 1915); Lodge and Shipley Machine Tool Company, Cincinnati, Ohio (plant engineer, 1916–17); Hercules Powder Company, Nitro, W. Va. (field supervisor, 1918); A. L. Drum and Company, Chicago, Ill. (valuation engineer, 1919); H. P. Gillette and Company, Chicago (valuation engineer, 1920); and R. M. Feustel and Company, Fort Wayne, Ind. (valuation engineer, 1921–22). In 1923 he went with the Tennessee Electric Power Company as a relay engineer, became superintendent of electrical operation in 1925, and superintendent of system operation in 1928. Mr. George has contributed to the technical press since 1919, has been very active in the Edison Electric Institute for many years, and is a member of the Institute of Radio Engineers. He was chairman of the East Tennessee Section of AIEE (1937–38) and served the Institute on the committees on protective devices (1928–31, 1935–37) and on communication (1936–39).

Albert Lange Turner (M'29) chief engineer of the Nebraska-South Dakota area of the Northwestern Bell Telephone Company, Omaha, Nebr., has been nominated to serve the Institute as vice-president representing the North Central District (number 6). Born at Owatonna, Minn., May 22, 1886, Mr. Turner started work in 1903 with the Northwestern Telephone Exchange Company at Owatonna and served that branch of the Northwestern system in various capacities from lineman to district plant chief. In 1919 he became plant chief of the Deadwood, S. Dak., district of the Nebraska Telephone Company and was later transferred to the Chaldron, Nebr., district. In 1920 he became construction engineer on the force of the division plant engineer at Omaha. The next year he was made exchange facilities engineer, on work covering the economic aspects as well as questions of engineering practice, with the chief engineer of the Northwestern Bell Telephone Company at Omaha. His subsequent titles were: engineer of outside plant estimates; engineer of transmission, protection, and foreign wire relations; engineer of plant extension; and chief engineer (since 1928). He served as chairman of the Nebraska Section of AIEE 1931–32.

Harry Williams Hitchcock (A'15, M'27, F'37) chief engineer of the Southern California Telephone Company, Los Angeles, has been nominated to serve the Institute as vice-president representing the Pacific District (number 8). Born January 1, 1890, at Lincoln, Nebr., Mr. Hitchcock received a bachelor of science degree from Pomona College in 1911, and later took two years' graduate work in physics and electrical engineering at Cornell University. From 1913 to 1921 he was in the transmission and development and research departments of the American Telephone and Telegraph Company, New York, N. Y. He left to do telephone transmission engineering with the Pacific Telephone and Telegraph Company at San Francisco, Calif., and worked with that company until 1924 when he went with the Southern California Telephone Company at Los Angeles. The first four years he was transmission and protection engineer but was made chief engineer in 1928. He has contributed to the technical press for many years. He served on the membership committee of the Institute (1933–35), and is a past chairman of the Los Angeles Section.

John Morton Thomson (A'26, M'30) chief designing engineer, Ferranti Electric, Ltd., Mount Dennis, Ont., Canada, has been nominated to serve the Institute as vice-president representing the Canada District (number 10). Born June 3, 1898, at Couva, Trinidad, British West Indies, Doctor Thomson was graduated from the University of Toronto in 1924. He later was awarded a master of applied science degree (1933) and a doctor of philosophy degree (1937) by that university. From 1920 to 1921 and during the summers of 1922 and 1923 he worked for the English Electrical Company of Canada at Toronto. He took the General Electric test course for graduate engineers (1924–25) and was made transformer designer with the English Electrical Company of Canada in 1925. He began his work with Ferranti Electric, Ltd., in 1926 as radio engineer and from 1928 to 1930 he was also responsible for the experimental and development work in connection with power and instrument transformers. Since 1930 he has been in charge of the designing department of that company, and has spent some time working in England. He has served the AIEE Canada District as secretary for several years. He is a member of the Institution of Electrical Engineers and of the Institute of Radio Engineers.

Eldredge, Hellmund, and Meyer Nominated for Institute Directorships

Mark Eldredge (A'14, M'20, F'33) chief engineer, Memphis Power and Light Company, Memphis, Tenn., has been nominated to serve the AIEE as a member of its board of directors. Born at Woodbury, N. J., May 17, 1882, Mr. Eldredge was graduated with a bachelor of science degree in electrical engineering from Worcester Polytechnic Institute, in 1906. He entered the testing department of the General Electric Company at Schenectady, N. Y., that year. In 1907 he was made an assistant electrical engineer in the United States Reclamation Service at Williston, N. Dak. From 1908 to 1911 he did varied electrical work in Utah and Colorado. He then went to Allahabad, India, where he was professor of electrical engineering at Ewing Christian College from 1911 to 1913. Next he became electrical assistant to the textile engineer, Tata Hydro-Electric Power Supply Company, Bombay, India, in 1913. From 1915 to 1917 he was distribution engineer with that company. In 1918 and 1919 he served as a captain in the United States Army at Port Clinton, Ohio. He returned to India in 1919 as superintendent of power with the Ludlow Jute Company at Calcutta. In 1922 he became assistant engineer with the Electric Bond and Share Company, New York, N. Y. He went with the Memphis Power and Light Company as chief engineer in 1924. He has been active over a period of years in the Edison Electric Institute and its predecessor organization, the National Electric Light Association. He was chairman of the Memphis Section of AIEE when it was organized (1930–31). He served as vice-president (1935–37) and was a member of the following committees: power transmission and

distribution (1933–39), Sections (1934–37), Institute policy (1937–38), safety (1937–39), and also served on the special committee for consideration of broadening of Institute activities (August to October 1936).

F. J. MEYER

MARK ELDREDGE

Bachrach

R. E. HELLMUND

Rudolf Emil Hellmund (A'05, M'09, F'13) chief engineer of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been nominated to serve the AIEE as a member of its board of directors. Born February 2, 1879, at Gotha, Germany, Mr. Hellmund was graduated from the Technical College of Ilmenau, Germany, as an electrical engineer in 1889 and did postgraduate work at the University of Charlottenburg, Berlin, in 1901 and 1902. He worked at the designing of electric machinery at Poeschmann, Cologne, and Stuttgart before coming to the United States in 1903. That year he was with Krantz Company, Brooklyn, N. Y., working on the designing of circuit breakers. In 1904 he assisted Grant B. Rossman in the designing of a telegraphic device for transmitting drawings, and in 1905 went to Great Barrington, Mass., where he became associated with William Stanley in the designing of induction motors and a self-compounding alternator. From 1905 to 1907 he was in the engineering department of the Western Electric Company at Hawthorne, Ill. In 1907 he entered the engineering department of the Westinghouse company as a designer of induction motors and his progress has been recognized by various changes in title. He has been a prolific writer on technical subjects and has more than 300 patents. He was awarded the 1929 Lamme Medal of the AIEE, and in 1933 he was appointed chief engineer of the Westinghouse company, a position that had been held vacant since the death of Mr. Lamme in 1924. Mr. Hellmund has traveled extensively, representing Westinghouse in foreign fields, and has become especially well known for his interest in the training of young men. He is serving the Institute as chairman of the standards committee and as a member of the committee of planning and co-ordination. He also represents the Institute on the electrical standards committee and is on the standards council of the American Standards Association.

Frank J. Meyer (A'13, M'17, F'36) vice-president in charge of operation, Oklahoma Gas and Electric Company, Oklahoma City, has been nominated to serve the AIEE as a member of its board of directors. Born at Grant City, Mo., July 12, 1884, Mr. Meyer was with the Oklahoma Gas and Electric Company as a meterman from 1901 to 1904. He was graduated from Pratt Institute, Brooklyn, in 1906, and spent 18 months in Porto Rico as assistant to the chief engineer of the Guanica Centrale Sugar Company at Guanica. In 1907 he returned to the Oklahoma Gas and Electric Company as chief electrician, became general superintendent in 1920, assistant to the general manager in charge of operation in 1924, and vice-president in 1931. Mr. Meyer was vice-president of the Institute from 1934 to 1936 and has served on the following committees: power transmission and distribution (1934–36); general power applications (1934–38); and Edison Medal (1935–40).

W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12) professor and head of the department of electrical engineering at Columbia University, New York, N. Y., has been renominated to serve the Institute as treasurer. Born May 7, 1873, at St. Paul, Minn., Professor Slichter was graduated from Columbia University in 1896 with the degree of electrical engineer. That year he entered the employ of the General Electric Company at Schenectady, N. Y. He spent one year in the testing department and five years as assistant to C. P. Steinmetz, doing experimental work and in the designing of all classes of a-c machinery, especially in the application of a-c motors to railway work. He then became assistant to the technical director, doing general engineering work of a consulting character as well as retaining charge of experimental work. In 1910 he began teaching electrical engineering at Columbia. From 1914 to 1917 he gave instruction to naval officers of the postgraduate school of the United States Navy on the design, construction, and operation of all electrical apparatus used on board naval vessels. Aside from serving the Institute as national treasurer since 1930, as manager (1918–22), and as vice-president (1922–24), he has acted on a great many committees.

W. D. COOLIDGE

W. L. R. EMMET

M. A. SAVAGE

M. A. Savage to Receive Lamme Medal

Marion A. Savage (A'21) designing engineer of the General Electric Company, Schenectady, N. Y., has been awarded the Lamme Medal of the AIEE for 1938 "for able and original work in the development and improvement of mechanical construction and the efficiency of large high-speed turbine alternators." He was born at Walterboro, S. C., September 3, 1885, and received the degree of bachelor of science in electrical engineering at Clemson College in 1906. After graduation he obtained experience, while employed by the General Electric Company, as a student engineer in 11 different departments. In 1909 he was transferred to the turbine generator section of the a-c engineering department, and in 1923 was placed in charge of the section. He became designing engineer of the department in 1931. A Coffin Award was bestowed on him in 1932, a portion of the notation on the award stating "Mr. Savage has shown outstanding ability in design and development of large steam-driven generators. His designs have done much to permit trebling of the size of turbines in a comparatively short time. This growth has resulted in problems and risks of increasing magnitude. The excellence of these generators and the freedom from complaints testify to the quality of the job that he has done." During the past four years he has directed the development and novel engineering associated with the building of 28 large turbine generators which are cooled by means of hydrogen. Technical papers written by him have appeared in various publications, and one was presented at the World Power Conference in Berlin. Nu-

merous patents relating to the construction of turbine generators have been awarded to him. The honorary degree of electrical engineer has been conferred upon him by Clemson College.

W. L. R. Emmet (A'93, HM'33) consulting engineer with the General Electric Company at Schenectady, N. Y., has received the David W. Taylor Medal awarded by the Society of Naval Architects and Marine Engineers for his "notable achievements in the advance and development of marine machinery, the most outstanding of which was the electric drive." Doctor Emmet was born July 10, 1859, at Pelham, N. Y., and was graduated from the United States Naval Academy in 1881. In 1910 the honorary degree of doctor of science was conferred on him by Union College, Schenectady, N. Y., and in 1925 a like honorary degree by Trinity College, Hartford, Conn. In 1887 he went with the Sprague Electric Railway and Motor Company, working in Richmond, Va., and Harrisburg and Pittsburgh, Pa. Later he was with the Westinghouse Electric and Manufacturing Company and with the Buffalo Railway Company, each for a short time, but went to Chicago, Ill., as district manager of the Edison General Electric Company after its formation. In 1892 he was transferred to New York as engineer in charge of the foreign department and was with the company when it became the General Electric Company. He holds more than 100 patents on electrical and allied apparatus, having done important work in steam turbine inventions and in the invention of the mercury-vapor power process. He was awarded the AIEE Edison Medal in 1919 and the Elliott Cresson Medal of the Franklin Institute in 1920. He served the AIEE as vice-president (1900–02) and as a member of several committees.

W. D. Coolidge (A'10, M'34) has been awarded the Faraday Medal for 1938 by the council of the Institution of Electrical Engineers (Great Britain). Doctor Coolidge, one of the foremost X-ray scientists in the world, was born at Hudson, Mass., October 23, 1873. He received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1896 and the degree of doctor of philosophy from the University of Leipzig in 1899. He combined teaching at Massachusetts Institute of Technology with research work with the General Electric Company for five years, leaving in 1905 to enter the research laboratories of the General Electric Company at Schenectady, N. Y. He became assistant director of research in those laboratories in 1908, associate director in 1928, and has been director since 1932. Doctor Coolidge received the Rumford Medal in 1914 for invention and application of ductile tungsten; the Howard N. Potts Medal in 1926; the Louis Edward Levy Gold Medal in 1926; the gold medal of the American College of Radiology in 1927; the Hughes Medal of the Royal Society, London, in 1927; the Edison Medal in 1927; the Washington Award in 1932; and the John Scott Medal in 1937. The Faraday Medal was founded in 1921 to commemorate the 50th anniversary of the first meeting of the Institution of Electrical Engineers and is awarded each year for notable scientific and industrial achievement in electrical engineering or for conspicuous service rendered to the advancement of electrical science.

P. M. Lincoln (A'95, F'12) has retired as director of the school of electrical engineering of Cornell University at Ithaca, N. Y., and now is head of the Therm-Electric Meter Company. Professor Lincoln was born at Norwood, Mich., January 1, 1870, and was graduated as a mechanical engineer in electrical engineering from Ohio State University in 1892. He was then employed by the Brush Electric Company at Columbus, Ohio, but at the end of that year left to enter the testing department of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. In 1895 he became electrical superintendent with the Niagara Falls Power Company, but in 1902 returned to Westinghouse to be in charge of the power division of the engineering department. He was appointed general engineer for the company in 1910, and remained there until 1919, at the same time being head of the engineering school of the University of Pittsburgh (1911–15). In 1919 he joined the firm of his brother, The Lincoln Electric Company of Cleveland, Ohio, as consulting engineer. In 1922 he became director of the school of electrical engineering at Cornell. His formal retirement took place in June 1938, but he continued as acting director until February 1, 1939. Professor Lincoln is a member of several scientific and engineering societies, and in 1902 was awarded the John Scott Medal for his invention of the synchroscope. He was a manager of the Institute from 1906 to 1909, vice-president from 1909 to 1911, and president from 1914 to 1915. He has also served on many committees of the Institute during the past quarter of a century.

W. A. Kietzman (M'23) has been appointed vice-president and general manager of the upstate area, New York Telephone Company, Albany. Born September 7, 1888, at Eau Claire, Wis., Mr. Kietzman was granted the degree of bachelor of science in electrical engineering by the University of Wisconsin in 1912. That year he entered the commercial engineering department of the American Telephone and Telegraph Company as a student engineer. He was advanced to assistant engineer and then to exchange rate practice engineer. During the World War he served in the motor equipment section and requirements division of the ordnance department of the United States Army and was a member of the Stettinius Mission to France. After his discharge with the grade of first lieutenant, Mr. Kietzman returned to the American Telephone and Telegraph Company as a cost engineer. In 1921 he went with the Bell Telephone Company of Pennsylvania at Philadelphia as general commercial engineer. Five years later he returned to the American Telephone and Telegraph Company as sales and directory engineer. He came to the New York Telephone Company in 1928 as general commercial manager of the Manhattan area, a position which he held until his recent promotion and transfer.

W. O. Turner (A'31) has been elected president and general manager of the Louisiana Power and Light Company, Algiers. Mr. Turner was born at Lonoke, Ark., March 19, 1897 and received the degree in electrical engineering from the University of Arkansas in 1919. From 1919 to 1922 he was resident engineer with the Little Rock Railway and Electric Company at Little Rock, Ark. In 1922 he became resident engineer and construction superintendent with the Phoenix Utility Company and in 1927 was made resident supervising engineer with Electric Bond and Share Company, doing work in Tennessee, Florida, and Louisiana. In 1928 he went with Louisiana Power and Light Company as chief engineer, was made a director of the company in 1933, and became vice-president in 1936.

W. A. Lewis, Jr. (A'27, M'29) has been appointed director of the school of electrical engineering in the College of Engineering at Cornell University, Ithaca, N. Y. Doctor Lewis was born at Harriman, Tenn., January 21, 1904, and in 1920 became an electrical draftsman and switchboard engineer with the Westinghouse Electric and Manufacturing Company at Los Angeles, Calif. In 1922 he received the Westinghouse War Memorial Scholarship contributing toward the four years' course in engineering at California Institute of Technology. He was granted a bachelor of science degree (with honor) in 1926, a master of science degree (with honor) in 1927; and a doctor of philosophy degree

P. M. LINCOLN

W. A. KIETZMAN

W. O. TURNER

in 1929, the only student of electrical engineering ever to receive that degree *summa cum laude* from that institution. As winner of a junior travel prize in 1925, he studied for one summer in Europe, but worked for the Westinghouse company during other summers when he was attending the university. Since 1929 he has been employed in the central station engineering department of the Westinghouse company at East Pittsburgh, Pa., specializing in transmission and problems relating to steam-railroad electrification. He has also been a Westinghouse lecturer in electrical engineering at the University of Pittsburgh and has given evening courses for engineers of several power and light companies. He has published articles on technical subjects and is co-author of a book on symmetrical components.

H. H. Weber (A'27, M'29) has been appointed commercial engineer of the wire sales department of the United States Rubber Company, New York, N. Y. Since 1934 he had been assistant manager of that department. Mr. Weber studied electrical engineering at Bliss Electrical School, Washington, D. C., and later attended Lehigh University. From 1917 to 1919 he served with the engineers corps of the United States Army in France and in the United States. In 1919 he was an engineer with the Utica Gas and Electric Company, but in 1920 became engineer and chief electrical inspector with the New York State Fire Insurance Rating Organization at Jamestown and Syracuse. In 1924 he went with the Rome Wire Company in Rome, N. Y., and was later transferred to that company's offices in New York City. Before going with the United States Rubber Company he had been director of low-voltage engineering with the General Cable Corporation, New York, since 1930.

A. A. Frank (A'03, M'31) has retired from the position of chief engineer of the New York Telephone Company, Manhattan area, New York. Born in New York City on September 14, 1877, Mr. Frank attended the College of the City of New York for 2½ years and then continued his education at Columbia University, graduating in 1900. In 1901 he became engineering assistant with the New York and New Jersey Telephone Company. Here he had an important part in the original subway engineering for Long Island and northern New Jersey. In 1909 he was made fundamental plans engineer with the New York Telephone Company and ten years later was given the title of engineer of fundamental plan and subway requirements. In 1920 he became engineer of exchange plant extension and was appointed chief engineer of downstate New York in 1925. He had served as chief engineer of the Manhattan area since 1927.

F. P. Lawrence (A'25) formerly vice-president and general manager of the upstate area has been transferred from Albany to New York by the New York Telephone Company to become vice-president and general manager of the Manhattan area. A student of civil engineering at Lehigh University in the class of 1910, Mr. Lawrence spent two years in the construction industry and then started his telephone career with the Southwestern Bell Telephone Company at St. Louis, Mo., in 1912. He entered the employ of the New York Telephone Company in 1929 as general plant manager in the upstate area and became vice-president and general manager of that area in 1934.

R. M. Morris (M'28) has been elected vice-president in charge of personnel operations, rates, and franchises by the Mountain States Telephone and Telegraph Company, Denver, Colo. Mr. Morris started with the Mountain States company in the

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plant department at Denver in 1905. He became wire chief at Cripple Creek in 1907 and manager in 1909. In 1910 he became district manager, located at Durango, but returned to Denver in 1916 as commercial engineer. The next year he went to Helena, Mont., as division commercial superintendent, but again returned to Denver in 1920 as commercial engineer and rate expert. In 1923 he became general commercial manager and previous to his present appointment had been assistant vice-president.

L. R. Milburn (A'20, M'31) has been elected chairman of the Detroit district section of the Association of Iron and Steel Engineers. A graduate of the University of Michigan, Mr. Milburn served with the United States Army signal corps in 1918. From 1919 to 1924 he was with the General Electric Company doing testing, sales, and engineering work at Schenectady, N. Y., and Cleveland and Cincinnati, Ohio. From 1924 to 1929 he did general electric engineering work on construction with the Louisville Gas and Electric Company, Louisville, Ky. In 1929 he became assistant electrical engineer for the Great Lakes Steel Corporation, Ecorse, Mich., was made acting electrical engineer in 1933, and electrical engineer in 1935.

E. M. Richards (M'25) has been made assistant vice-president in charge of operations by the Republic Steel Corporation, Cleveland, Ohio. Mr. Richards was graduated with the degree of bachelor of science in electrical engineering from Bucknell University in 1913 and was awarded the honorary degree of electrical engineer in 1919. He went with the Westinghouse Air Brake Company, Pittsburgh, Pa., as a testing engineer. In 1915 he was made assistant to the chief engineer and in 1917, assistant to the manager of engineering. From 1920 to 1925 he was with H. O. Swoboda, Inc., Pittsburgh, Pa., first as consulting electrical and mechanical engineer and then as vice-president. In 1925 he went with the Jones and Laughlin Steel Corporation at Aliquippa, Pa., as chief industrial engineer, but left to occupy a like position with the Republic Steel Corporation in 1930. He had been assistant to the vice-president since 1935.

G. C. Barney (M'37) has been transferred to the department of operation and engineering (transmission section) of the American Telephone and Telegraph Company, New York, N. Y. Mr. Barney was graduated from the University of Maine in 1924 with a degree in electrical engineering. During 1918 and 1919 he had charge of radio operations at Poitiers, France, and during 1920 and 1921 in Vienna, Austria. He went with the New England Telephone and Telegraph Company at Providence, R. I., in 1926. In 1929 he came to New York in the transmission engineer's department of the American Telephone and Telegraph Company. Since 1935 he has been located in London, England, as assistant to the technical representative in Europe.

R. S. Bailey (M'31) has been appointed price survey engineer, reporting to the operating results engineer of the American Telephone and Telegraph Company, New York, N. Y. He was graduated from Lowell Institute as an electrical engineer in 1917 and later took night work at Massachusetts Institute of Technology. Mr. Bailey started with the New England Telephone and Telegraph Company in 1908, working in Lowell during the time he went to school. In 1919 he entered the engineering department of the American Telephone and Telegraph Company in New York. He holds many patents on circuit arrangements for telephone switching systems.

C. M. Brentlinger (A'19, M'27) has been appointed general superintendent of traffic of the Western Union Telegraph Company, New York, N. Y. Born December 10, 1893, at Freelandville, Ind., Mr. Brentlinger was graduated from the University of Illinois in

C. M. BRENTLINGER

1916 with the degree of bachelor of science in electrical engineering. That year he went with the Western Union Telegraph Company, New York, as engineering assistant in the office of the vice-president in charge of traffic. His progress in the company was marked by the following changes in title: general inspector in 1920, general traffic supervisor in 1928, and central division traffic superintendent in 1931. During the seven years that he held the last-named position, Mr. Brentlinger made his headquarters at Omaha, Nebr.

R. C. Newhouse (A'31) has been awarded the Lawrence Sperry Award for 1938 by the Institute of Aeronautical Sciences "for the development and first practical application of the terrain clearance indicator." Mr. Newhouse was graduated from Ohio State University with the degree of bachelor of electrical engineering in 1929 and received the degree of master of science in 1930 while continuing at Ohio State University as a fellow under the Guggenheim Fund for the Promotion of Aeronautics. Since 1930 he has been a member of the technical staff of the Bell Telephone Laboratories, Inc. New York, N. Y., engaged in radio transmitter development.

A. F. Rose (A'19, M'22) has been made electrical engineer in charge of the toll group of the American Telephone and Telegraph Company, New York, N. Y. Graduated from Colorado College in 1914 with the degree of bachelor of science in electrical engineering, Mr. Rose has been continuously employed by the company since that time. He has had responsibility for important electrical engineering work having to do with the use of telephone repeaters on open wire and cable circuits as used by the Bell System. Until recently he was in charge of the exchange and special services group.

D. H. Robinson (M'36) has been made executive engineer of the construction division of the public works department, electricity branch, at Lahore (Punjab), India. Mr. Robinson was born at Wolstanton Stoke on Trent, England, October 17, 1892, and received his education at Armstrong College, Durham University. His work as an engineer (aside from that done in England, Scotland, and Wales) has taken him to foreign fields for long periods of years. After experience in Berlin, Siam, Egypt, and the Straits Settlements, he went to India in 1934, and until recently was at Amritsar.

R. A. Galbraith (A'38) has transferred from the staff of the electrical engineering department of the University of Missouri, Columbia, to the staff of the University of Texas, Austin, as assistant professor of electrical engineering. Mr. Galbraith received the degree of bachelor of science in electrical engineering at the University of Missouri in 1933 and was awarded the degree of doctor of philosophy by Yale University in 1937. From 1937 to 1938 he was an electrical engineer in the research department of the Detroit Edison Company at Detroit, Mich.

T. W. Eadie (A'27) has been made western division plant supervisor of the Bell Telephone Company of Canada. Mr. Eadie was graduated from McGill University with a degree in civil engineering. During the summers he had been employed by the Bell company on power developments and in 1923 started regular employment in the fundamental engineer's office of that company. He became toll and transmission engineer of the central division in 1927. Prior to his recent appointment, he had been general plant supervisor at Toronto.

O. P. Cleaver (A'36) has been appointed a member of the executive committee of the Better Light-Better Sight Bureau. Mr. Cleaver was graduated from Georgia School of Technology in 1928 and was granted a master of science degree in electrical engineering by Yale University in 1930. Since that time he has been an illuminating engineer with the Westinghouse Electric and Manufacturing Company at Bloomfield, N. J., and is now in charge of the commercial engineering department of the lamp division.

J. A. Mathews (A'37) is now junior engineer with the United States Bureau of Mines, Central Experiment Station, Pittsburgh, Pa. He received the bachelor of science of electrical engineering degree from the University of Maryland in 1928 and the master of science degree in electrical engineering from Massachusetts Institute of Technology in 1930. Previous to this recent appointment he was an instructor at Wyomissing Polytechnic Institute, Wyomissing, Pa.

Robert Loewe (A'32) is now employed as an electrical engineer with the Commonwealth and Southern Corporation at Jackson, Mich. Mr. Loewe took his electrical engineering work at the University of Wisconsin, graduating in 1930 and later continuing graduate work there. He had been employed as distribution transformer design engineer with the Westinghouse Electric and Manufacturing Company at Sharon, Pa.

P. H. Williams (A'35) has been appointed district plant superintendent with the American Telephone and Telegraph Company at Detroit, Mich. Mr. Williams received a bachelor of science degree from the University of Minnesota in 1922. His entire professional experience has been with the long lines department of the American Telephone and Telegraph Company. Just previous to this change he was area plant supervisor, Chicago, Ill.

R. F. Davis (A'25) has been placed in charge of the exchange and special services group of the American Telephone and Telegraph Company, New York, N. Y. He was graduated as an electrical engineer from Cornell University in 1921 and has been in the engineering department of the American Telephone and Telegraph Company since that time. Until recently he had been in charge of the electrical co-ordination group (transmission section).

B. K. Boyce (A'10, M'28) formerly chief engineer of the upstate area, has been transferred from Albany to New York by the New York Telephone Company and is now chief engineer of the Manhattan area. Mr. Boyce has been with the New York Telephone Company ever since his graduation from Cornell University in 1907. He had been chief engineer of the upstate area since 1926. He served the Institute on the committee on communication, 1930–31.

H. P. Sherer (A'35) was named among the winners of the 1938 awards of the James F. Lincoln Arc Welding Foundation. His paper concerning fans for electrical machines received fourth award in subclass *J-3*, functional machinery, electrical. An electrical engineering graduate of Ohio State University in 1934, Mr. Sherer is employed by Imperial Electric Company, Akron, Ohio.

David Sarnoff (M'23) was presented with the Gold Medal Achievement Award of the Poor Richard Club (advertising) at Philadelphia, Pa., on January 17, 1939, in "recognition of outstanding contributions to the advancement of American industry." Mr. Sarnoff has been president of the Radio Corporation of America, New York, N. Y., since 1930.

G. F. Stark (A'38) is now electrical engineer with the Stark Electrical Company of Baltimore, Md. A graduate of Johns Hopkins University in 1937, Mr. Stark had been employed as an electrical engineer with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. and with the Westinghouse Electric International Company, New York, N. Y.

Macklen Kleiman (A'37) has been made engineer and assistant to the president of the Melrose Curtain Company, Inc., Boston, Mass. Graduated from the Massachusetts Institute of Technology as an electrical engineer in 1936, Mr. Klieman had been a welding engineer in the Lycoming Division of the Aviation Manufacturing Corporation at Williamsport, Pa.

Vannevar Bush (A'15, F'24) has been elected to life membership in the corporation of the Massachusetts Institute of Technology. Doctor Bush was formerly vice-president and dean of engineering of Massachusetts Institute of Technology and is now president of the Carnegie Institution, Washington, D. C.

L. R. Schumacher (A'32) is now junior engineer on hydroelectric power plant design with the Bureau of Reclamation at Denver, Colo. Mr. Schumacher was graduated from South Dakota State College in 1930 and had been a junior engineer with the United States Engineers at Fort Peck, Mont.

B. H. Carter (A'31) has been made field engineer with the Rural Electrification Administration at Madison, Wis. He had previously been a junior engineer with the United States Engineers at Zanesville, Ohio. He received his degree in electrical engineering from Ohio State University in 1929.

G. V. Harrap (A'34) has been made technical assistant to the West Ham Corporation Electricity Department at West Ham,

London, England. He was formerly assistant engineer in the Corporation Electricity Department at Hull, Yorkshire, England.

W. E. Brainard (A'33) has been employed as plant superintendent of the Weldrods Corporation at Cuyahoga Heights, Ohio. He was graduated from Cornell University in 1931 and had been production engineer with the Wilson Welder and Metals Company, Inc., at North Bergen, N. J.

R. E. Higgins (A'35) who has been with the Santa Fe Railroad at Needles, Calif., since 1931, recently has been made maintenance foreman of that company's ice plant at Bakersfield, Calif. Mr. Higgins was graduated from the University of California in 1928.

T. W. Reynolds (A'36) now is employed as development engineer by the Bendix Aviation Corporation at Bendix, N. J. He was formerly an engineer in the experimental department of the Pioneer Instrument Company, Brooklyn, N. Y.

F. E. Swift (A'16, M'30) has been transferred by the civil service department of the State of Michigan from Newberry State Hospital, Newberry, to the State Prison of Southern Michigan at Jackson as steam electric engineer.

A. J. Fischer (A'36) is now metallurgist with American Cutting Alloys at Lewiston, Maine. A graduate of Pratt Institute in 1934, Mr. Fischer was formerly metallurgist with the Metal Powders Processing Company, Inc., Long Island City, N. Y.

F. W. Atkinson (A'31, M'37) electrical engineer with the Owens-Illinois Glass Company at Newark, Ohio, is now, since the formation of a new company, with the Owens-Corning Fiberglas Corporation.

Obituary

Cary Talcott Hutchinson (A'90, M'90, F'12) died at Coral Gables, Fla., January 16, 1939. Doctor Hutchinson was born March 4, 1866, at St. Louis, Mo., and was graduated from Washington University, St. Louis, in 1886. He received the degree of doctor of philosophy from Johns Hopkins University in 1889. From 1889 to 1891 he was with the Sprague Electric Railway Company and was closely associated with the designing and building of the first electric locomotive in the United States for use in the Chicago freight terminals. From that time until 1923 he was engaged in practice as a consulting engineer, the firm name from 1892 to 1894 having been Sprague, Duncan, and Hutchinson. Much of his work was with commissions working on the electrification of railways, among the most important having been the Baltimore and Ohio, the Great Northern, the Northern Pacific, the Rapid Transit of New York City, the Illinois Central, and the Maine Central. From 1906 to 1908 he was engaged by the Great Northern Railway in the design and construction of the electric equipment of its road over the Cascade Mountains, one of the first three-phase electrifications to be built in the United States. He also did pioneer work in studying the possibilities of hydroelectric development of the Susquehanna River, his efforts resulting in the underwriting and construction of the dam and power station at McCall Ferry, Pa., a plant which supplies Baltimore with electric service and has transmission lines extending to Safe Harbor, York, and Coatesville, Pa. In 1923 Doctor Hutchinson joined the engineering firm of Sanderson and Porter, New York, as associate consulting engineer. Here he was active on electric light, power, and transmission and transportation work until his retirement in 1932. Doctor Hutchinson contributed widely to publications on the electrification of railroads and was the first secretary of the National Research Council and of the Engineering Foundation, having served both of those bodies during the World War. He was a manager of the Institute (1895–98), vice-president (1898–1900), and served on the National Research Council, division of engineering (1925–29). He was also a member (1925–26) of the committees on transportation and meetings and papers.

Charles Shumway Ruffner (A'02, M'08, F'12) died at Fort Meyers, Fla., January 21, 1939. Mr. Ruffner was born June 22, 1880, at Chicago, Ill., and was graduated from the University of Missouri in 1900. He started work that summer with the Missouri Edison Company of St. Louis, but in September went with the Telluride Power Company, working in Utah and Colorado. From 1909 to 1911 he was with the Central Colorado Power Company at Denver and from 1911 to 1913 with the Mississippi River Power Distributing Company of St. Louis. From 1914 to 1916 he was vice-president of the Electric Company of Missouri at Webster Groves and from 1917 to 1919, vice-president of the Union Light and Power Company, St. Louis. In 1919 he became vice-president of the North American Company which controlled the Union Electric Light and Power Company. In 1921 he became vice-president and general manager of the Adirondack Power and Light Company; in 1925, president of the Mohawk-Hudson Power Company; and in 1927, president of the New York Power and Light Corporation. He had been vice-president of the Niagara-Hudson Power Company while serving in other capacities in that group. He retired in 1929 but remained chairman of the board of directors of the Schenectady Trust Company, Schenectady, N. Y. Mr. Ruffner served the Institute as a manager (1916–20), as vice-president (1920–21), and was active on many committees.

Paul Doty (A'04, M'12) died December 3, 1938. Born May 30, 1869, at Hoboken, N. J., Mr. Doty was graduated from Stevens Institute of Technology in 1888 with the degree of mechanical engineer, but later took special work in electrical engineering at the University of Colorado. From 1888 to 1895 he was with the United States Gas Improvement Company, starting as a cadet engineer in the Philadelphia, Pa. plant and being later transferred to Jersey City and Paterson, N. J. From 1895 to 1898 he was vice-president and general manager of the Consolidated Gas Company of New Jersey, Long Branch. In 1903 he took a similar position with the Denver Gas and Electric Company, Denver, Colo. In 1904 he went with the McMillin interests and was vice-president and general manager of the Edison Electric Light and Power Company, St. Paul, Minn.; vice-president of the St. Croix Power Company, St. Croix, Wis.; and vice-president and general manager of the St. Paul Gas Light Company, and from 1905 to 1910 was president of the Union Light, Heat and Power Company of Fargo, N. Dak. In 1917 he relinquished his various utility interests to serve the United States in the World War. He was a major in the corps of engineers from 1917 to 1919 and was detailed to give advice on construction projects for the army to the Secretary of War. In 1919 he was commissioned lieutenant-colonel, a title which he subsequently held in the reserve corps of the United States Army. He was also brigadier general on the general staff corps of the Minnesota National Guard. At the time of his death Mr. Doty was chairman of the Minnesota Board of Registration for Architects and Engineers, St. Paul, and had been active in civic affairs over a period of years.

William Thomas Ryan (A'07, M'12) died February 5, 1939. Professor Ryan was born at Bristol (now Joice), Iowa, February 28, 1882, and was graduated in electrical engineering from the University of Minnesota, Minneapolis, in 1905. For two years he was with Westinghouse Electric and Manufacturing Company at Salt Lake City, Utah, and the General Electric Company, Schenectady, N. Y. In 1907 he returned to the University of Minnesota as an instructor in the engineering department, was made assistant professor in 1909, associate professor in 1919, and had been professor of electric power engineering since 1922. He was the author of a three-volume work on the design of electrical machinery and of many technical papers. During the years he was with the university, he also did consulting work in Minnesota and South Dakota and served on the Minnesota Tax Commission. He was vice-president of the Institute from 1928 to 1930 and served on the following committees: production and application of light (1928–30) and education (1929–33). He was active in the work of the Minnesota Section of AIEE and was serving as chairman of the local District meeting committee at the time of his death.

Hugh Julius Glaubitz (M'17) assistant professor at the school of technology of the College of the City of New York, New York, died on January 14, 1939. Doctor Glaubitz was born in Neunmuenster, Germany, in 1875 and came to the United States in 1892. He was graduated from the University of Pittsburgh in 1896 with a degree in civil engineering. He started work as a structural designer with Carnegie Steel Company, Pittsburgh, Pa., in 1896 and became a United States citizen in 1898. From 1898 to 1901 he was with Julian Kennedy, Pittsburgh, Pa.; a con-

sulting engineer on blast furnace, coke oven, and rolling mill construction. From 1901 to 1903 he was again with Carnegie Steel Company as construction engineer of blast furnaces; and for a short time in 1903 he was with the Lackawanna Iron and Steel Company as an engineer. From 1904 to 1908 he was with the National Electric Signaling Company, doing design and construction work on wireless plants and assisting in the management of European affairs. From 1908 to 1911 he was a consulting engineer at Toronto, Canada, working on high-voltage transmission lines and water works. From 1911 to 1915 he was general manager of the Public Utilities Commission, London, Canada, acting as consulting engineer on electrical and water works. He became vice-president of The Sothman Corporation, New York, in 1915. From 1918 to 1928 he was engaged in independent consulting work and in 1928 became division engineer with the Public Service Production Company, Newark, N. J. In 1933 he engaged in teaching at Nassau Collegiate Center and from September 1936 until his death had been at the College of the City of New York.

William Francis Dawson (A'05, M'13, F'29) died January 17, 1939. Mr. Dawson was born at Andover, Mass., February 10, 1868. In 1886 he was graduated from the school of mechanic arts conducted by Massachusetts Institute of Technology, and later took courses at Lowell Institute. He served a three-year apprenticeship as machinist in the locomotive repair shops of the Boston and Albany Railroad, at Boston. In 1890 he entered Thomson-Houston Electric Company at Lynn, Mass., which company was later consolidated with the Edison General Electric Company. In 1894 he was transferred to Schenectady, N. Y., as a draftsman and from 1895 to 1905 he was in the engineering department, where he had an important part in the designing of d-c generators. From 1905 to 1910 he was at Rugby, England, in charge of the designing of d-c motors and generators for the British Thomson-Houston Company, Ltd. In 1910 he returned to the General Electric Company at Schenectady, and the next year was transferred as a designing engineer to the generator section of the river works turbine section at West Lynn, Mass., where he remained until his retirement. He was responsible for many improvements in turbine generators. During the past few years Mr. Dawson had been living at Holliston, Mass.

Clarence Irving Brown Henning (A'13) died on January 26, 1939, at Berkeley, Calif. Born at Los Gatos, Calif., May 31, 1881, Mr. Henning was graduated from the California School of Mechanical Arts, San Francisco, in 1898 and attended the University of California. In 1901 Mr. Henning went with the California Powder Works at Pinole, having gained his first experience in the chemistry of explosives as assistant to the dean of the college of chemistry of the University of California. He was first employed by the E. I. du Pont de Nemours and Company, Inc., at the Haskell (N. J.) smokeless powder plant in 1907 and later became internationally known as a smokeless powder chemist. In 1913 he was appointed ballistics engineer at the company's experimental station in Wilmington, Del. In 1917 he was technical adviser on explosives to the British Ministry of Munitions in London. From 1921 until his retirement in 1932, Mr. Henning was assistant director of military sales in charge of technical matters of the explosives department of the du Pont Company at Wilmington. For several years Mr. Henning was president of the Sporting Arms and Ammunition Manufacturers' Institute and was a member of the National Rifle Association.

Michael Wittenberg (M'24) who had been engaged in the insurance business in New York, N. Y., for more than a decade, died in January 1939. Born August 20, 1873, at Polotzk, Russia, Mr. Wittenberg attended the University of Bern, Switzerland, and received his degree in electrical engineering at the Polytechnicum, Darmstadt, Germany. After doing consulting work for various municipal administrations in Russia from 1902 to 1904, he became vice-president and manager of Electricheskaya Energia, in St. Petersburg. In 1906 he became associated with the Russian Westinghouse company at St. Petersburg, but left in 1913 to join the Russian General Electric Company at Moscow in the department of planning and installation of large power plants. From 1920 until he came to the United States in 1924 he was chief electrician with the Concessioners of the Electric Light and Tramway System, Harbin, Manchuria. In the United States Mr. Wittenberg was with the Pennsylvania Power and Light Company at Allentown a short time before he left electrical engineering for insurance work.

Frederick William Insull (M'37) died at Tulsa, Okla., on January 14, 1939. Mr. Insull was born in England, July 5, 1875, and received his education in the public schools of Winnipeg, Canada. In 1902 he became secretary and treasurer of the Evanston Electrical Illuminating Company, Evanston, Ill. From 1902 to 1909 he was secretary and treasurer of the North Shore Electric Company (now the Public Service Company of Northern Illinois) at Chicago. In 1909 he was auditor for the Northern Idaho and Montana Power Company and in 1910 and 1911 auditor with the H. M. Byllesby Company at Portland, Ore., and then auditor for the Arkansas Valley Light and Power Company at Pueblo, Colo. (1911–12). In 1913 he founded and became president of the Public Service Company of Oklahoma, a position which he held until his death, concurrently having been vice-president or president of several affiliated companies of the Midwest Utilities group.

Robert Carr Lanphier, Sr. (A'01, M'07, F'13) died January 28, 1939, at Springfield, Ill. Born January 25, 1878, at Springfield, he was graduated from Yale University with a degree of bachelor of philosophy in electrical engineering in 1897. For the first two years following graduation he was engaged in the development of electric meters in the shops of the Illinois Watch Company in Springfield, but in 1899, with Jacob Bunn, founded and organized the Sangamo Electric Company. He started as superintendent and electrical engineer, became secretary and manager in 1906, and later was made vice-president. Upon the death of Mr. Bunn in 1926 he became president, a post he held until his death. British Sangamo, Ltd., was organized in 1920 at Enfield, England, and the Canadian branch was established at Toronto in 1930.

Nelson E. Buck (A'19) died December 12, 1938. Born January 22, 1884, at Elgin, Ill., Mr. Buck studied electrical engineering through the International Correspondence Schools. From 1901 to 1902 he was engineer with the Elgin Public Schools and for a short time with the Elgin Manufacturing Company. Later in 1902 he became substation operator with the Aurora, Elgin, Chicago Railway. In 1903 he became electrician with the Sterling Boiler Company and later that year, chief engineer with the Barberton Electric Company. In 1905 he started as substation operator with Commonwealth Edison Company and worked with that company in various capacities until his death. Since 1915 he had been superintendent of the underground division in the construction department at Chicago, Ill.

Samuel Noble Roberts (A'21) died in January 1939 at Atlanta, Ga. He was born June 21, 1886, at Anniston, Ala., and studied at the Georgia School of Technology. From 1907 to 1909 he was with Westinghouse Electric and Manufacturing Company. From 1909 to 1910 he was employed by the Southern Iron and Steel Company at Gadsden, Ala., but during the last six months of 1910 was with the United States Cast Iron Pipe and Foundry Company, Anniston, Ala. From 1911 until his death he was with the Atlantic Steel Company at Atlanta, Ga. Starting as chief electrician, he became electrical and mechanical superintendent in 1920, a position which he held until his death.

Charles Frederick Hopewell (A'97, M'18) died October 17, 1938. Born at Boston, Mass., June 1, 1872, Mr. Hopewell was graduated as an electrical engineer from Massachusetts Institute of Technology in 1894. That year he went with Goodall Worsted and Sanford Mills, Sanford, Maine, but the next year was employed in the testing department of the Stanley Electric Company at Pittsfield, Mass. From 1895 to 1903 he was city electrician, Cambridge, Mass. He then did experimental work as a partner in the Uni Signal Company for two years. From 1905 until his recent retirement he was a member of the firm of Hopewell Brothers, manufacturers of automobile specialties at Watertown, Mass.

Glendon C. Brown (M'37) electrical engineer with Cutler-Hammer, Inc., Milwaukee, Wis., died in 1938. Mr. Brown was born January 2, 1907, at Fargo, N. Dak., and was graduated from the University of Minnesota with the degree of bachelor of science in electrical engineering in 1928. That year he entered Cutler-Hammer, Inc., as a research engineer. He was granted many patents on electronic speed regulators and controllers and other original designs.

Membership

Recommended for Transfer

The board of examiners, at its meeting on February 16, 1939, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Bingham, L. A., assistant professor of electrical engineering, University of Nebraska, Lincoln.
Browder, J. D., assistant electrical engineer, Oklahoma Gas and Electric Company, Oklahoma City.
Galphin, C. B., engineer, R. H. Bouligny, Inc., Charlotte, N. C.
Huber, G. H., member of technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.
Lyons, J. M., assistant design engineer, General Electric Company, West Lynn, Mass.
Monseth, I. T., southwestern engineering manager, Westinghouse Electric and Manufacturing Company, St. Louis, Mo.
Rudelius, C. B., junior engineer, Northern Indiana Public Service Company, Hammond.

7 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1939, or May 31, 1939, if the applicant resides outside of the United States or Canada:

United States and Canada

Abfalter, E. J., Detroit Edison Company, Detroit, Mich.
Abrams, H. W., Argo Lamp Company, Philadelphia, Pa.
Adams, C. M., General Electric Company, Pittsfield, Mass.
Adamson, R. G., Philadelphia Electric Company, Philadelphia, Pa.
Ajello, M. F., Westinghouse Electric and Manufacturing Company, Los Angeles, Calif.
Albing, G. K., Erie Electric Motor Company, Buffalo, N. Y.
Alfers, J. B., Rural Electrification Administration, Washington, D. C.
Alsaker, A. E., Richardson-Wayland Electric Company, Pulaski, Va.
Ames, F. H., Jr., Westinghouse X-Ray Company Inc., Chicago, Ill.
Anderson, L. W., North Electric Manufacturing Company, Galion, Ohio.
Angell, A. W., Jr., General Electric Company, Schenectady, N. Y.
Ansel, R. M., Public Works Administration, Chicago, Ill.
Antrim, M. B., 414 Luzerne Avenue, West Pittston, Pa.
Applegate, C. E., Dominion Electrical Manufacturing Company, Mansfield, Ohio.
Arter, R. C., North Electric Manufacturing Company, Galion, Ohio.
Ashman, H. E., North Electric Manufacturing Company, Galion, Ohio.
Askren, J. W., General Electric Company, York, Pa.
Athey, V. C., Wauneta Light and Power Company, Wauneta, Nebr.
Babel, P. V. R., International Business Machines Corporation, Endicott, N. Y.
Badger, B. E., United States Army Engineers, Fort Peck, Mont.
Bailey, A. D., care of K. R. Brown, Des Moines, Iowa.
Bailey, R. B., Louisiana Power and Light Company, Algiers.
Barber, W. L., 104 Sitgreaves Street, Phillipsburg, N. J.
Barton, H. J., Jr., The B-L Electric Manufacturing Company, St. Louis, Mo.
Basler, D. E., Rural Electrification Administration, Washington, D. C.
Baumhardt, G. L. R., 2027 Mars Avenue, Lakewood, Ohio.
Beach, J. M., Northwestern Bell Telephone Company, Des Moines, Iowa.
Bednarz, F. J., care of K. R. Brown, Des Moines, Iowa.
Bender, L., North Electric Manufacturing Company, Galion, Ohio.
Bennison, G. K., P. O. Box 4, Houghton, Mich.
Benowitz, H. S., 1315 Lafayette Ave., Bronx, N. Y.
Benoist, T. M., Pacific Gas and Electric Company, San Francisco, Calif.
Benz, F. D. (Member), United States Rubber Company, San Francisco, Calif.
Bergler, R. J., E. R. Squibb and Sons, Brooklyn, N. Y.
Bergseth, F. R., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.
Bevan, J. E., Roller Smith Company, Bethlehem, Pa.
Bilotta, J. E., 435 Roseville Avenue, Newark, N. J.
Bimm, E. E., Hydro Electric Power Commission of Ontario, Toronto, Canada.
Blackett, H. W., Canadian Westinghouse Company, Hamilton, Ont.
Blackhall, J. P. M., North Electric Manufacturing Company, Galion, Ohio.
Blackstone, H., San Diego Consolidated Gas and Electric Company, San Diego, Calif.
Boatwright, L. T., Jr., Company No. 2432 CCC, Mars Hill, N. C.
Bohn, A. L., 2540 Windsor Avenue, Dubuque, Iowa.
Bohn, J. T., Pittsburgh Plate Glass Company, Tarentum, Pa.
Bollone, P., Chandeysson Electric Company, St. Louis, Mo.
Bond, M. W., Mississippi State Highway Department, Jackson.
Bonds, E. R., Robert and Company, Inc., Atlanta, Ga.
Bonnar, J. G., North Electric Manufacturing Company, Galion, Ohio.
Bopp, J. M., Box number 405, Bay Saint Louis, Miss.
Bosler, G. E., North Electric Manufacturing Company, Galion, Ohio.
Bowie, W. B., Electric Storage Battery Company, Pittsburgh, Pa.
Boykin, E. M., Texas Electric Service Company, Big Spring.
Branson, N. G., Shell Petroleum Corporation, Houston, Tex.
Brooke, E., North Electric Manufacturing Company, Galion, Ohio.
Breese, L. R., North Electric Manufacturing Company, Galion, Ohio.
Brown, H. C., J. T. Ryerson & Son, St. Louis, Mo.
Brown, W. D., Hydril Company of Pennsylvania, Rochester.
Brown, W. E., Colt's Patent Firearms Manufacturing Company, Hartford, Conn.
Brown, W. H., Duke Power Company, Shelby, N. C.
Brunmer, B. C., American Telephone and Telegraph Company, Denver, Colo.
Brunelly, J., Jr., 24-45 32 Street, Long Island City, N. Y.
Brunette, C. L. J., 208 Baker Street, Sudbury, Ont., Canada.
Brydahl, I. L., Otter Tail Power Company, Wahpeton, N. Dak.
Buchanan, D. V., Brooklyn Edison Company, Inc., Brooklyn, N. Y.
Burke, R. F., Jr., Main Street, Williamsburg, Mass.
Burrall, W. P., Automatic Electric Company, Chicago, Ill.
Burriss, S. W., Otis Elevator Company, New York, N. Y.
Cade, M. J., New Orleans Public Service, Inc., New Orleans, La.
Caldwell, J. J., Jr., Sperry Gyroscope Company, Brooklyn, N. Y.
Campbell, R. T., North Electric Manufacturing Company, Galion, Ohio.
Carr, J. E., General Electric Company, Pittsfield, Mass.
Carstens, C. W., Public Works Administration, Chicago, Ill.
Cassel, W. M., Philadelphia Electric Company, Philadelphia, Pa.
Cavanagh, J. G., Jr., Illinois Iowa Power Company, Urbana, Ill.
Chernoff, J. L., 1212 Beverly Road, Brooklyn, N. Y.
Chesley, J. W., Jr., Consolidated Gas and Electric Company, Baltimore, Md.
Chinlund, D. K., Illinois Bell Telephone Company, Chicago.
Christiansen, A. G., United States Engineers Office, Fort Peck, Mont.
Christopher, J. B., Ohio Power Company, Newark.
Clarke, W. H., Sidney Inlet Mining Company, Vancouver, B. C., Canada.
Cline, J. E., Gorrell and Gorrell, Grand Rapids, Mich.
Cohen, J., 910 26th Avenue, Seattle, Wash.
Cook, H. M., Jr., Clark Controller Company, Cleveland, Ohio.
Coon, H. B., 911 Penn, Boulder, Colo.
Cordray, R. E., General Electric Company, Philadelphia, Pa.
Coughlin, W. B., Board of Transportation, City of New York, N. Y.
Cox, C. F., Jr., Phillips Petroleum Company, Bartlesville, Okla.
Cresmer, W. J. (Member), University of Maine, Orono.
Cummins, A. E., Halliburton Oil Well Cementing Company, Duncan, Okla.
Cyrus, H. N., Water and Light Commission, Greenville, N. C.
Dauberman, W. H., Bucknell University, Lewisburg, Pa.
Davis, G. E., North Electric Manufacturing Company, Galion, Ohio.
Dayton, A. M., 1029 National Avenue, Toledo, Ohio.
DeHuff, C. B., Southwestern Light and Power Company, Lawton, Okla.
Deininger, C. F., Dallas Power and Light Company, Dallas, Tex.
DeNise, D. D., City Light Department, Seattle, Wash.
Deshaw, B. F., University of British Columbia, Vancouver, Canada.
de Socio, G. P., 2647 North Charles Street, Baltimore, Md.
Diggs, R. S., Philadelphia Electric Company, Philadelphia, Pa.
Dimpfl, R. W., Rochester Telephone Corporation, Rochester, N. Y.
Distel, M., 2700 Bronx Park East, New York, N. Y.
Donati, E. T., Massachusetts Institute of Technology, Cambridge.
Drexel, C. L., North Electric Manufacturing Company, Galion, Ohio.
Dudzienski, S. H., 1711 Dahill Road, Brooklyn, N. Y.
Duhamel, H. G., North Electric Manufacturing Company, Galion, Ohio.
Duim, A. R., American Gas Association, Los Angeles, Calif.
Dukes, W. W., Jr., United States Navy Yard, Charleston, S. C.
Dupont, G. H., Jr., 48 Kempson Place, Metuchen, N. J.
Dyche, H. E., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Easley, G. P., Roosevelt County Electric Membership Corporation, Portales, N. M.
Eberhard, E., South Dakota State College, Brookings.
Eisendrath, D. C., General Electric Company, Schenectady, N. Y.
Elliott, S. J., Jr., Bell Telephone Laboratories, Inc., New York, N. Y.
Ellis, R. H. (Member), United Engineering and Foundry Company, Pittsburgh, Pa.
Erzenik, F., Jr., 318 Second Street Northeast, Mason City, Iowa.
Essigmann, M. W., Northeastern University, Boston, Mass.
Evans, L. O., Jr., Idaho Power Company, Twin Falls.
Everett, B. L., Commonwealth Edison Company, Chicago, Ill.
Everhart, J. G., Line Material Company, Zanesville, Ohio.
Ewing, P. B., Indiana Bell Telephone Company, Indianapolis.
Faus, R. R., Electrical Products Corporation of Oregon, Portland.
Falls, W. H., Hygrade Sylvania Corporation, Salem, Mass.
Farneman, J. D., Weston Electrical Instrument Corporation, Los Angeles, Calif.
Ferrell, A. A., Tennessee Electric Power Company, Chattanooga.
Fomberstein, L., Moderne Watch Strap Company, New York, N. Y.
Ford, W. A., Missouri Power and Light Company, Mexico.
Fosholt, S. K., Young & Stanley Inc., Muscatine, Iowa.
Francy, R. A., Weirton Steel Company, Weirton, W. Va.
Frantz, D. R., Washington Institute of Technology College Park, Md.
Freeman, C. W., North Electric Manufacturing Company, Galion, Ohio.
Fritzsche, W. R., Richmond Screw Anchor Company Inc., Brooklyn, N. Y.
Fromke, F. A., Union Public Service Company, Canby, Minn.
Furlow, W. M., Jr., E. P. McLean Engineering Company, Moultrie, Ga.
Gardner, G. N., New Market, Ind.
Gardner, V. B., Continental Motors Corporation, Muskegon, Mich.
Garratt, R. W., 40 Sylvan Place, Nutley, N. J.
Garrettson, E. P., Consolidated Edison Company of New York, Inc., New York.
Gates, A. M., Philadelphia Electric Company, Philadelphia, Pa.
Gaty, L. R., Philadelphia Electric Company, Philadelphia, Pa.
Gatzke, I. H., United States Civil Service Commission, Washington, D. C.
Gebuhr, J. V., 803 Valley Bank Building, Des Moines, Iowa.
Gerard, J. W., care of Harry Huebner, RR No. 3, Evansville, Ind.
Glassman, I., Philadelphia Navy Yard, Philadelphia, Pa.
Glowasky, A., Lydon Brothers, Jersey City, N. J.

Goldberg, E. A., Magnolia Petroleum Company, Dallas, Texas.
Gollub, L., Bell Telephone Company of Pennsylvania, Philadelphia.
Goodman, J., 409 Amboy Street, Brooklyn, N. Y.
Goodwin, G. H., Niagara, Lockport and Ontario Power Company, Buffalo, N. Y.
Goodwin, L. C., Durham Public Service Company, Durham, N. C.
Gosnell, J. L., Locke Insulator Corporation, Baltimore, Md.
Gragg, C. W., Panhandle Power and Light Company, Borger, Tex.
Graham, E. M., Jr., 1273 Peachtree Street, Atlanta, Ga.
Graham, J. E., Sola Electric Company, Chicago, Ill.
Granlund, E. A., Puget Sound Navy Yard, Seattle, Wash.
Graybill, H. R., 1021 Daisy Avenue, Long Beach, Calif.
Greek, D. D., Davega Radio Company, New York, N. Y.
Green, H. C., Navy Yard, Charleston, S. C.
Greenwood, R. I., Phelps Dodge Corporation, Jerome, Ariz.
Gregory, H. S., University of Florida, Gainesville.
Greve, T. E., Houston Lighting and Power Company, Houston, Texas.
Griffin, K. H., Box 33, Chilocco, Okla.
Guinee, C. R., Jr., Cornell-Dubilier Electric Corporation, South Plainfield, N. J.
Gutshall, R. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Hackett, J. F., National Broadcasting Company, Cleveland, Ohio.
Hale, K. M., Shelley Electric Company, Wichita, Kans.
Hamilton, J., 3700 Coldwater Canyon Road, North Hollywood, Calif.
Hammerquist, R. C., Hammerquist Electric Company, Moline, Ill.
Hammond, R. E., III, Pennsylvania Electric Company, Johnstown.
Hansbrough, S. S., Potomac Edison Company, Hagerstown, Md.
Hardy, D. C., Jr., El Paso Electric Company, El Paso, Tex.
Harrell, J. W., 619 North Estelle, Wichita, Kans.
Harrington, H. H., North Electric Manufacturing Company, Galion, Ohio.
Harrison, A. E., California Institute of Technology, Pasadena.
Hart, G. F., Bangor Hydro Electric Company, Bangor, Maine.
Hartsook, R. W., Line Material Company, Zanesville, Ohio.
Hartwell, G. C., Birdseye Electric Company, Gloucester, Mass.
Harvey, F. K., Bell Telephone Laboratories, Inc., New York, N. Y.
Harvey, I. M., Metropolitan Edison Company, Reading, Pa.
Hassler, E. W., General Electric Company, Pittsfield, Mass.
Haubner, R. H., University of Toronto, Toronto, Ont., Canada.
Haupt, Irwin, 138 South Ninth Street, Philadelphia, Pa.
Hayer, F. W., Missouri Power and Light Company, Moberly.
Hayward, F. W., General Motors Corporation, Milford, Michigan.
Heagler, E. F., Moloney Electric Company, St. Louis, Mo.
Heggem, M., Texas New Mexico Utilities Company, Abernathy.
Held, W., Portsmouth Navy Yard, Portsmouth, N. H.
Herbst, J. A., North Electric Manufacturing Company, Galion, Ohio.
Herrald, A. E., Schlumberger Well-Surveying Corporation, Long Beach, Calif.
Herwig, R. F., care of K. R. Brown, Des Moines, Iowa.
Hesling, D. M., Sealed Power Corporation, Muskegon, Mich.
Heverly, L. F., York Ice Machinery Corporation, York, Pa.
Hieronymus, J. W., Public Service Company of Northern Illinois, Wheaton.
Higley, R. E., Hydril Company of Pennsylvania, Rochester.
Hillyer, C., Jr., Burrows Pillopak Corporation, Glendale, Calif.
Holdsworth, W. W., Fire Department, City of New York, N. Y.
Holloway, V. C., Public Service Company of Indiana, Lafayette.
Holst, G. E., Reynolds Electric Company, Brooklyn, N. Y.
Holt, A., National Park Service, Waterloo Project, Chelsea, Mich.
Honeywell, C. C., Bucknell University, Lewisburg, Pa.
Hoover, H. H., Ohio Brass Company, Mansfield.
Horrell, R. F., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Horton, E. V., General Electric Company, Schenectady, N. Y.
Hubard, H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Hughes, G. N., Aluminum Company of America, Alcoa, Tenn.
Hull, W. B., Whitestown, Ind.
Hull, W. D., Steuben County Farm Bureau Cooperative Association, Angola, Ind.
Ileman, E. A., Roller Smith Company, Bethlehem, Pa.
Iskow, S., 1924 North Moore Street, Rosslyn, Va.
Ittes, J. J., Ohio Brass Company, Barberton.
Ives, G. M., Jr., Station WCLS, Inc., Joliet, Ill.
Jacobsen, W. E., General Electric Company, Schenectady, N. Y.
Jancar, T. A., Simplex Radio Co., Sandusky, Ohio.
Jay Cobb, H., Ferranti Electric, Inc., New York, N. Y.
Jenkinson, H. T., Pittsburgh Railways Company, Pittsburgh, Pa.
Johannessen, J., Imperial Irrigation District, Imperial, Calif.
Johannsen, R. H., United States Engineers, Fort Logan, Colo.
Johnson, A. W., Illinois-Iowa Power Company, Ottawa, Ill.
Johnson, L. L., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Jones, W. W., Magnolia Petroleum Company, Dallas, Tex.
Jong, S. G., 474 University Avenue, Toronto, Ont., Canada.
Joseph, H. M., United States Civil Service Commission Building, Washington, D. C.
Kaczmarek, J. J., Indiana and Michigan Electric Company, South Bend, Ind.
Kahan, G. G., 141 Park Place, New York, N. Y.
Kaluk, N. S., Pocahontas Fuel Company Inc., Switchback, W. Va.
Karle, P., North Electric Manufacturing Company, Galion, Ohio.
Keith, R. B., American Steel and Wire Company, Worcester, Mass.
Kennedy, E. R., Route 9, Box 476, Seattle, Wash.
Kent, J. F., Jr., Canavan and Lang, Chicago, Ill.
Kerstein, J. D., Micamold Radio Corporation, Brooklyn, N. Y.
Ketchum, P. M., General Electric Company, Schenectady, N. Y.
Kiefer, W. M., Commonwealth Edison Company, Chicago, Ill.
Kimball, L. W., North Road, Bedford, Mass.
Kingman, R. W., Purchase Street, South Easton, Mass.
Kirloskar, R. L., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Klein, G. W., Whiteman Sign Co., Winona Lake, Ind.
Kleppinger, W. D., Sr., Consolidated Edison Company of New York, Inc., New York, N. Y.
Knowlton, H. E. (Member), Raytheon Production Corporation, Newton, Mass.
Koontz, W. R., Pacific Gas and Electric Company, San Francisco, Calif.
Korhone, E. D., Ideal Electric and Manufacturing Company, Mansfield, Ohio.
Kornblith, L., Jr., 1163 Scott Avenue, Winnetka, Ill.
Kotowitsch, V., Automatic Electric Company, Chicago, Ill.
Kovac V. B., 161–0329 Avenue, Flushing, N. Y.
Kruger, R. M., King Music Company, Denver, Colo.
Krzysciak, B. J., A. Dalkin Company, Chicago, Ill.
Kyte, C. H., Federal Shipbuilding and Drydock Company, Kearny, N. J.
Lamming, J. H., Commonwealth Edison Company, Chicago, Ill.
Lane, R. B., Jr., Arkansas Power and Light Company, Pine Bluff.
Laplant, K. A., Narragansett Electric Company, Providence, R. I.
Lathrop, E. M., Dishman, Wash.
Lawley, J. K., Southwestern Light and Power Company, Lawton, Okla.
Lawrence, W. E., Jr., Duke Power Company, Charlotte, N. C.
Lee, J. R., Vanadium Corporation of America, Niagara Falls, N. Y.
Lehman, A. T., Bell Telephone Company of Canada, Toronto, Ont.
Lehrer, A., Stelton, N. J.
Leigh, H. H., Box 253, Espanola, N. Mex.
Leslie, H. A., Panhandle Power and Light Company, Borger, Tex.
Leslie, J. R., Hydro Electric Power Commission of Ontario, Toronto, Canada.
Levada, A. R., National Sugar Refining Company, Long Island City, N. Y.
Levy, H. C., Halliburton Oil Well Cementing Company, Houston, Tex.
Lindahl, M. A., General Electric Company, Pittsfield, Mass.
Linde, L. J., General Electric Company, Philadelphia, Pa.
Lindon, P. H., Fort Lewis School, Hesperus, Colo.
Lingard, A., Fort Monmouth, Oceanport, N. J.
Lingo, A. A., United States Engineers, Fresno, Calif.
Linn, C. A., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Linton, R. E., Halliburton Oil Well Cementing Company, Houma, La.
Lisberger, T. S., General Electric Company, Philadelphia, Pa.
Lisle, C., Mansfield Telephone Company, Mansfield, Ohio.
Lister, B. C., Sheldon, Iowa.
Little, A. J., Public Service Company of Oklahoma, West Tulsa.
Little, R. H., Tennessee Valley Authority, Guntersville Dam, Ala.
Lloyd, R. C., 2042 Dwight Way, Berkeley, Calif.
Lorens, S. A., North Electric Manufacturing Company, Galion, Ohio.
Louie, A. C., Pacific Electric Company, Los Angeles, Calif.
Loutit, J. A., Dominion Electrohome Industries Ltd., Kitchener, Ont., Canada.
Lowery, D. T., Rural Electrification Administration, Washington, D. C.
Luchini, O. J., Consumers Power Company, Alma, Mich.
Maas, A. W., Seismograph Service Corporation, Tulsa, Okla.
Manion, R. T., Commonwealth Edison Company, Chicago, Ill.
Manville, A. R., J. Livingston and Company, New York, N. Y.
Martin, E. T., Virginia Polytechnic Institute, Blacksburg.
Martin, R. A., New York Power Corporation, Syracuse, N. Y.
Mandl, G. P., Drexel Institute of Technology, Philadelphia, Pa.
Matlack, R. C., T. W. Phillips Gas and Oil Company, Butler, Pa.
Matthew, S. M., Carnegie Illinois Steel Corporation, Chicago, Ill.
Matthews, J. H., Jr., Electric Storage Battery Company, Pittsburgh, Pa.
Maxwell, J. S., Citizens' Conservation Corps., Company 1442, Dresden, Tenn.
Mazur, D. G., 19 Westbourne Parkway, Hartford, Conn.
McCorkle, N. M., Mississippi State College, State College.
McCoy, R. C., Hover, Wash.
McDonald, M. T., care of K. R. Brown, Des Moines, Iowa.
McDonough, B. W., 16 Hickory Street, Terryville, Conn.
McGraw, C. (Member), Texas-New Mexico Utilities Company, Plainview, Tex.
McGuire, C. E., Gatineau Power Company, Low, Que., Canada.
McKale, T. P., Commonwealth Edison Company, Chicago, Ill.
McKay, J. E., Roller Smith Company, Bethlehem, Pa.
McLeish, C. W., National Research Laboratories of Canada, Ottawa, Ont.
McMaster, R. C., Case School of Applied Science, Cleveland, Ohio.
McShea, W. T., United States Civil Service, Navy Department, New York, N. Y.
Meek, C. K., 6622 South Cheyenne, Tacoma, Wash.
Meihof, A. D., Northwestern Electric Company, Portland.
Michel, M., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Mickelson, G. A., Deerfield, Wis.
Miller, A. S., R. W. Cramer Company, Inc., New York, N. Y.
Miller, T. F., Wald Manufacturing Company, Inc., Maysville, Ky.
Mills, C. R., care of A. S. Norcross, Watertown, Mass.
Mindes, A. S., Davega City Radio, Inc., New York, N. Y.
Mitchell, H. F., Jr., Government Printing Office, Washington, D. C.
Mitschrich, M. F. (Member), Moloney Electric Company, St. Louis, Mo.
Miulo, J., The Pacific Lumber Company, Scotia, Calif.
Mock, C. H., Henningson Engineering Company, Omaha, Nebr.
Mogle, W. S., Jr., Dallas City Water Works, Dallas, Tex.
Moloney, T. O., Jr., Moloney Electric Company, St. Louis, Mo.
Monson, S. H., Jr., 2874 Chadbourne Road, Cleveland, Ohio.
Morgan, R. H., 317 North Fullerton Avenue, Montclair, N. J.
Moore, C. R., Gulf Oil Corporation, Johnstown, Pa.
Morrill, A. R., Caldwell Engineering Company, Jacksonville, Ill.
Mount, B. H., Jr., 24 Maple Street, Princeton, N. J.
Mueller, F. M., A. Y. Taylor and Company, Clayton, Mo.
Muir, D. G., General Cable Corporation, Perth Amboy, N. J.
Mullen, J. J., Jr., Moloney Electric Company, St. Louis, Mo.
Munson, L. J., Joslyn Manufacturing and Supply Company, Chicago, Ill.
Murdoch, W. W., Jr., Southern Utah Power Company, Cedar City.
Murphy, C. J., North Electric Manufacturing Company, Galion, Ohio.
Murphy, S. A., Jr., University of California, Berkeley.
Nawn, P. M., International Harvester Company, Milwaukee, Wis.
Nechemias, H. B., Wagner Electric Corporation, St. Louis, Mo.
Nelson, W. K., United States Forest Service, Portland, Ore.
Nethken, H. J. (Member), Louisiana Polytechnic Institute, Ruston, La.
Nettell, F. L., Pacific Gas and Electric Company, San Rafael, Calif.
Nicholas, J. H., Ohio Brass Company, Barberton.
Nicholas, R. V., Jr., Seismograph Service Corporation, Tulsa, Okla.
Niggemyer, F. W., Electric Controller and Manufacturing Company, Cleveland, Ohio.
North, H. C., Standard Oil Development Company, Elizabeth, N. J.
Oberholtzer, J. R., Rural Electrification Administration, Washington, D. C.
Oliver, S. W., Puget Sound Navy Yard, Bremerton, Wash.

Oschs, N., 518 North Jefferson Street, Mt. Union, Pa.

O'Riordan, C. F., Allis-Chalmers Manufacturing Company, Atlanta, Ga.

Orrick, L. S., Geophysical Service, Inc., Dallas, Tex.

Ortner, M., Jr., Monroe Electric Company, Chicago, Ill.

Oxaal, A., North Electric Manufacturing Company, Galion, Ohio.

Oxsvath, D. K., 189 Greenridge Avenue, White Plains, N. Y.

Palka, G. A., Federal Emergency Administration of Public Works, Chicago, Ill.

Papes, J. P., 101 Elmwood Avenue, Ithaca, N. Y.

Parce, J. R., Washington Gas Light Company, Washington, D. C.

Patterson, G. E., General Electric X-Ray Corporation, San Francisco, Calif.

Patton, F. A., North Electric Manufacturing Company, Galion, Ohio.

Pearce, R. B., KTRH Broadcasting Company, Pasadena, Tex.

Permut, A. A., Animating Products, Inc., Denver, Colo.

Peterson, F. W., Pacific Electric Manufacturing Company, San Francisco, Calif.

Pfleiderer, C. A. (Member), Indiana Bell Telephone Company, Indianapolis.

Philpott, L. A., Patten, Maine.

Picstil, J. G., Allis-Chalmers Manufacturing Company, Milwaee, Wis.

Pierce, G. C., R. H. Macy and Company, Inc., New York, N. Y.

Pierson, J. E., East Tawas, Mich.

Plucknett, E. J., Rural Electrification Administration, Washington, D. C.

Plummer, M. A., Bureau of Power and Light, Los Angeles, Calif.

Polzin, A., Chilhowee, Mo.

Pons, W., Duke Power Company, Burlington, N. C.

Porterfield, A. W., Jr., Electric Storage Battery Company, New York, N. Y.

Porterfield, R. H., State of Nebraska, Department Roads and Irrigation, Lyons.

Posey, R. P., Triplett Electrical Instrument Company, Bluffton, Ohio.

Powell, N. A., Taylor Instrument Companies, Cleveland, Ohio.

Pratt, W. E., Memphis Light and Water Division, Memphis, Tenn.

Preen, M. A. E. L. and A. G. Preen, Lebanon, N. J.

Pruett, J. W., 812 East 56th Street, Seattle, Wash.

Purpura, E. P., 160 East 65th Street, New York, N. Y.

Radford, R. A., Utah Power and Light Company, Rexburg, Idaho.

Reed, R. W., Union Steam Pump Company, Battle Creek, Mich.

Reingold, H. 1206 Chisholm Street, Bronx, N. Y.

Revilla, R., Jr., 2523 Ridge Road, Berkeley, Calif.

Richter, R. F., Inland Empire Rural Electrification, Inc., Spokane, Wash.

Ridgway, J. R., Jr., Houston Lighting and Power Company, Houston, Tex.

Rippere, J. B., General Electric Company, Pittsfield, Mass.

Roach, J., Carter Oil Company, Tulsa, Okla.

Roberts, D. S., Snoqualmie Falls Lumber Company, Snoqualmie, Wash.

Robertson, A. D., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.

Robinson, R. C., Canadian General Electric Company, Peterboro, Ont., Canada.

Romayne, R. C., Illinois Bell Telephone Company, Springfield.

Rouge, F. K., Electric Products Company, Cleveland, Ohio.

Rowland, J. F., Consolidated Edison Company of New York, Inc., New York, N. Y.

Rubenstein, D., care of H. A. Kaufmann, 963 Penobscot Building, Detroit, Mich.

Russo, R., Clark Controller Company, Cleveland, Ohio.

Rutter, J. R., Illinois Bell Telephone Company, Chicago.

Ryburn, F. W., Magnolia Petroleum Company, Dallas, Tex.

Ryon, H. C., North Electric Manufacturing Company, Galion, Ohio.

Sample, B., Jr., Houston Lighting and Power Company, Houston, Tex.

Saunders, B. M., Platte Valley Public Power and Irrigation District, North Platte, Nebr.

Schachte, W. L., Jr., Navy Yard, Charleston, S. C.

Schaefer, L. C., Westinghouse Electric and Manufacturing Company, Lima, Ohio.

Schaevitz, H., Navy Yard, Philadelphia, Pa.

Schalia, E. C., Navy Department, Washington, D. C.

Scheetz, J. R., General Electric Company, Schenectady, N. Y.

Schnabel, A. E., Consolidated Edison Company of New York, Inc., New York, N. Y.

Schumer, A. J., Fischbach and Moore, Inc., New York, N. Y.

Scott, J. N., Rhode Island State Highway Planning Survey, Providence.

Seider, S., Joe Hornstein Inc., New York, N. Y.

Settle, C., WPA National Research Project, Washington, D. C.

Severance, D. P., Massachusetts Institute of Technology, Cambridge.

Shanahan, E. F., Southern California Law School, Los Angeles.

Shapiro, H., University of Pittsburgh, Pittsburgh, Pa.

Sheadel, J. M., Ohio Brass Company, Barberton.

Sheckels, G. D., United States Bureau of Fisheries, Seattle, Wash.

Shelor, G. M., care of G. Morton, Greenville, S. C.

Shorter, C. H., Southern States Co-operative, Brooklyn, Md.

Shuler, J. H., North Electric Manufacturing Company, Galion, Ohio.

Sigler, B. M., Sigler Electric Company, Mobile, Ala.

Silverman, I. I., care of Maurice S. Cayne, Chicago, Ill.

Silvius, W. P., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Skidmore, W. H., Weston Electric Instrument Corporation, Newark, N. J.

Sloat, W. R., care of James G. Cooney, Belleville, Ill.

Sobkoviak, J. L., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Sodaro, J. F., Public Works Administration, Chicago, Ill.

Sokolov, E., Detroit Civil Service Commission, Detroit, Mich.

Soule, R. M., El Paso Electric Company, El Paso, Tex.

Spalinger, E. L., General Electric Lamp Works, East Boston, Mass.

Spencer, N. S., Virginia Public Service Company, Arlington.

Spinks, A. W., National Bureau of Standards, Washington, D. C.

Spragins, F. K., The Carter Oil Company, Tulsa, Okla.

Stafford, H. N., Texas Electric Service Company, Eastland.

Steigelman, E. T., Citizens' Conservation Corps, Company 4788, Ontario, Ore.

Steinbrook, S. E., Navy Yard, Philadelphia, Pa.

Sterrett, C. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Sterrett, K. R., North Electric Manufacturing Company, Galion, Ohio.

Stevenson, G. C., Boiler Inspection and Insurance Company of Canada, Toronto, Ont., Canada.

Stiefel, K., Worcester Polytechnic Institute, Worcester, Mass.

Stocker, C. P., Lorain Products Corporation, Lorain, Ohio.

Strobel, H. M., 10 Bridge Street, New York, N. Y.

Studley, J. H., Aluminum Company of America, Alcoa, Tenn.

Summerfield, D. N., Delco Products, Dayton, Ohio.

Suplin, N., Bureau of Power and Light, Los Angeles, Calif.

Suydam, J. W., Bayport, N. Y.

Swanson, S. C., 2442 East Grand, Des Moines, Iowa.

Swift, M., Public Service Electric and Gas Company, Elizabeth, N. J.

Swoish, W. R., Roller Smith Company, Bethlehem, Pa.

Sylvester, J. D., University of Alberta, Edmonton, Alba., Canada.

Taragin, S., Baltimore Polytechnic Institute, Baltimore, Md.

Thews, R. F., 442 Lincoln Street, Sturgeon Bay, Wis.

Thiessen, G. W., 1483 State Street, Schenectady, N. Y.

Thrithart, J., Illinois Iowa Power Company, Champaign.

Thompson, J. D., 444 Wolfs Lane, Pelham Manor, N. Y.

Tillotson, L. C., Bunker Hill and Sullivan Mining Company, Kellogg, Idaho.

Tooker, H. A., Ward Leonard Electric Company, Mt. Vernon, N. Y.

Tully, E. R., 150 Kentucky Avenue, Lexington, Ky.

Turk, R. J., Great Northern Railway Company, Spokane, Wash.

Turner, E. A., Hydro Electric Power Commission of Ontario, Niagara Falls, Canada.

Vasge, E. F. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.

Vander Veen, R., Ranger Engineering Corporation, Farmingdale, N. Y.

Van Valkenburgh, P., North Electric Manufacturing Company, Galion, Ohio.

Vestal, D. M., Jr., Humble Oil and Refining Company, Baytown, Tex.

Veterneck, J. S., 803 Valley Bank Building, Des Moines, Iowa.

Vierheller, A. P., Washington University, St. Louis, Mo.

Vinson, S. B., Ideal Electric and Manufacturing Company, Mansfield, Ohio.

Vulliet, F. O., United States Forest Service, Radio Laboratory, Portland, Ore.

Waddell, R. A., 9 Maple Road, Winthrop, Mass.

Waidelich, D. L., University of Missouri, Columbia.

Wainwright, L. F., Young and Stanley Inc., Muscatine, Iowa.

Walker, R. M., El Paso Electric Company, El Paso, Tex.

Walsh, N. B., Duquesne Light Company, Pittsburgh, Pa.

Warburton, R. W., Nevada Consolidated Copper Corporation, Ruth.

Ware, J. C., Kentucky-West Virginia Power Company, Ashland, Ky.

Washburn, M. A., Ford Bacon and Davis, Inc., New York, N. Y.

Wasson, O. G., Munn Electric Company, Ames, Iowa.

Watson, A. E., 207 East Sixth Street, Hutchinson, Kans.

Watts, J. M., Tennessee Valley Authority, Knoxville.

Weaver, J. G., North Electric Manufacturing Company, Galion, Ohio.

Weaver, R. C., A. K. Wilson Company, Oakland, Calif.

Weaver, R. T., United States Bureau of Reclamation, Denver, Colo.

Weems, J. H., Jr., Mississippi State College, State College.

Weibel, W. A., Central States Power and Light Corporation, West Union, Iowa.

Wells, H. F., Commonwealth Edison Company, Chicago, Ill.

Werts, R. W., Metropolitan Edison Company, Reading, Pa.

White, R. L., Interborough Rapid Transit Company, New York, N. Y.

Whitley, J. B., Humble Oil Company, Houston, Tex.

Wickens, S. M., 140 Mill Street, Athens, Ohio.

Wilcox, R. B., Commonwealth Ed son Company, Chicago, Ill.

Williams, A. W., Floyd County Rural Electric Co-operatives, Inc., Floydada, Tex.

Williams, G. L., Ohio Power Company, Ironton.

Williams, H. B., Knox Porcelain Corporation, Knoxville, Tenn.

Wilson, H. C., Canadian General Electric Company, Peterboro, Ont., Canada.

Wiseman, R. B., North Electric Manufacturing Company, Galion, Ohio.

Wollenweber, L. H., Indianapolis Power and Light Company, Indianapolis, Ind.

Wood, W. H., Jr., Commonwealth Edison Company, Chicago, Ill.

Wren, J. B., Jr., 1507 Wareman Avenue, Pittsburgh, Pa.

Woodburn, C. B., North Electric Manufacturing Company, Galion, Ohio.

Woodcock, R. E., Robey Manufacturing Company, East Lansing, Mich.

Woods, G. B., Ohio State University, Columbus.

Young, R. B., Jr., United States Engineers, Memphis, Tenn.

Young, R. S., Hydro Electric Power Commission of Ontario, Markham, Canada.

Yunck, F. F., Indiana & Michigan Electric Company, South Bend, Ind.

Zimmerman, H. B., 6425 12th Avenue, Kenosha, Wis.

Zimmermann, H. J., Washington University, St. Louis, Mo.

Total, United States and Canada—492

Elsewhere

Antippa, F. G., American University, Beirut, Syria.

Goldsman, J. L., J. L. Goldsman Ltd., London E.C.1, England.

Gray, L. R., General Electric Company, Rio de Janeiro, Brazil, S. A.

Karve, G. V., Tata Hydro Electric Company, Kalyan (G. I. P. Rly.), India.

Leggett, J. R., Socony-Vacuum Oil Company, Cairo, Egypt.

Macfarlane, J. W. (Member), Macfarlane Engineering Co. Ltd., Glasgow, Scotland.

Niwao, J., Hilo Electric Light Company, Hilo, Hawaii.

Pietri, A., Department of Interior, Government of Puerto Rico, Rio Piedras.

Rios, J. R., Cuban Telephone Company, Havana, Cuba.

Romeu, A. M. G., Cia Cubana De Electricidad, Havana, Cuba.

Sanchez, R. A., Cuban Mining Company, Cristo, Oriente, Cuba.

Tejada, L. H., Casilla 675, La Paz, Bolivia, South America.

Wang, S. J., A. Reyrolle & Co. Ltd., Hebburn-on-Tyne, England.

Wanner, R., Cerro de Pasco Copper Corporation, Malpaso, Peru, S. A.

White, P. E. P., Standard Telephones and Cables Ltd., London, England.

Total, elsewhere—15

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bertolacci, R. L., 721 Brighton Road, Pittsburgh Pa.

Coleman, Irwin M., 581 Academy St., New York, N. Y.

Cory, Harold M., 270 Washington Ave., Albany, N. Y.

Ebert, Kenneth W., 776 N. Cass St., Milwaukee, Wis.

Hyman, Stanley L., 156 Medway St., Providence, R. I.

McWhorter, W. Allen, Jr., 4549 Lake Park Ave., Chicago, Ill.

Straley, Munro R., Soldier, Pa.

Van Bylevelt, J. S., 220 E. 204th St., New York, N. Y.

8 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

AIR NAVIGATION. By P. V. H. Weems. Second edition. New York and London, McGraw-Hill Book Company, 1938. 587 pages, illustrated, 9 by 6 inches, leather, $5.00. Covers fundamental concepts, equipment, methods and practice of navigation by dead reckoning, blind flying, and the various systems of celestial navigation.

(The) CAUSES of ECONOMIC FLUCTUATIONS. By W. I. King. New York, Ronald Press Company, 1938. 353 pages, illustrated, 8 by 6 inches, cloth, $3.50. Business depressions are considered from the economic point of view. The author, after describing the characteristics of depressions, discusses various misleading or inadequate explanations of their origin and offers a further explanation, a summé of forces which influence depressions, and possible ways to forecast and minimize depression.

MODERNE MEHRGITTER-ELEKTRONENRÖHREN. Volume 2. Elektrophysikalische Grundlagen. By M. J. O. Strutt. Berlin, J. Springer, 1938. 143 pages, illustrated, 10 by 6 inches, paper, 13.20 rm. Modern multigrid electron tubes are considered from the theoretical viewpoint.

PUBLIC UTILITY RATE MAKING and the PRICE LEVEL. By E. M. Bernstein. Chapel Hill, University of North Carolina Press, 1937. 142 pages, tables, 9 by 6 inches, cloth, $2.50. The purpose of this study is to show how the rate making rule and its procedure were developed, to consider the difficulties experienced under this rule, to discuss the new methods of rate making that commissions used during the period of rapid fluctuation in prices, and to offer a reasonable solution for the problem of rate making.

STANDARDS on TRANSMITTERS and ANTENNAS, 1938. New York, Institute of Radio Engineers, 1938. 42 pages, diagrams, 9 by 6 inches, paper, $0.50. Pertinent terms are defined, graphical symbols are depicted, the factors to be considered in various methods of testing transmitters and antennas are discussed, and there is a brief section on the propagation of radio waves.

VDE-FACHBERICHTE, Volume 10, 1938 (with Inhaltskarten). Berlin-Charlottenburg 4, ETZ-Verlag. 214 pages, illustrated, 12 by 8 inches, paper, 12 rm. VDE-FACHBERICHTE Inhaltsverzeichnis der Bände 1-10 (1926-1938). 23 pages. Contains the papers presented at the 1938 annual meeting of the Verband deutscher Elektrotechniker. Sixty reports are included, discussing transmission, power lines, power-station construction, electric motor drives, electric heating, measurements, insulating materials, electrophysics, control and protection, telegraphy and telephony, and radio. Accompanying the book is an index to the first ten volumes of this series.

WELDED STEEL CONSTRUCTION. By R. S. Hale. New York and Chicago, Pitman Publishing Corporation, 1938. 170 pages, illustrated, 9 by 6 inches, cloth, $3.00. Aims to provide a simple, concise presentation of welded steel construction, adapted to the needs of engineers, contractors, and others familiar with structural engineering who are interested in the possibilities of welding in that field.

WINDING ALTERNATING-CURRENT MOTOR COILS. By G. A. Van Brunt and A. C. Roe. New York and London, McGraw-Hill Book Company, 1938. 281 pages, illustrated, 9 by 6 inches, cloth, $3.00. Explains and illustrates practical methods of designing, laying out, winding, and insulating the coils used in modern motors, and is intended to assist in the modernizing of older types of generators and motors and the repairing of present-day designs. A chapter is included on the properties and applications of glass-fiber insulating materials.

A.C. MOTORS of FRACTIONAL HORSEPOWER. By H. H. Jones. New York, Chemical Publishing Co., 1938. 189 pages, illustrated, 8 by 6 inches, cloth, $3.00. The working principles of fractional horsepower a-c motors are described and information is given for the construction, coil winding, testing, and repair of such motors. A special chapter is included on silencing and the suppression of radiated interference.

Die ELEKTROLYTISCHE OXYDATION des ALUMINIUMS und SEINER LEGIERUNGEN Grundlagen und Richtlinien für die praktische Durchführung der Eloxalverfahren. (Technische Fortschrittsberichte, Bd. 42, 1938). By A. Jenny. Dresden and Leipzig, Verlag von Theodor Steinkopff, 1938. 224 pages, illustrated, 9 by 6 inches, paper, 10.50 rm. A general account of current methods of protecting aluminum and its alloys from corrosion and chemical processes of protection.

FUNDAMENTAL ELECTRONICS and VACUUM TUBES. By A. L. Albert. New York, Macmillan Co., 1938. 422 pages, illustrated, 9 by 6 inches, cloth, $4.50. The material contained in this textbook is primarily for beginning study and can be described briefly as covering the following subjects: Fundamental principles of electronics and related phenomena; the electronic principles of vacuum (including gas) tubes; the use of vacuum tubes as circuit elements; photoelectric devices, cathode-ray tubes, and measurements.

Die GLEICHRICHTERSCHALTUNGEN, ihre Berechnung und Arbeitsweise. By W. Schilling. Munich and Berlin, R. Oldenbourg, 1938. 279 pages, illustrated, 10 by 7 inches, cloth, 17.50 rm. Rectifier connections are discussed comprehensively, both from the mathematical and the graphical viewpoints. Single and polyphase connections are considered under varying conditions of control, inductance, and method of loading. Examples, including tables and graphs, are presented.

Great Britain. Mines Dept. FIRE at DUMBRECK COLLIERY, STIRLINGSHIRE. Reports by T. Ashley and J. A. B. Horsley. London, His Majesty's Stationery Office, 1938. 27 pages, illustrated, 10 by 6 inches, paper (obtainable from British Library of Information, 270 Madison Ave., New York), $.45. Two special official reports concerning the causes of and the circumstances attending a colliery fire. The colliery is briefly described and the electrical system discussed with reference to the fire.

GRUNDZÜGE der SCHWEISSTECHNIK, Kurzgefasster Leitfaden. By T. Ricken. Berlin, J. Springer, 1938. 63 pages, illustrated, 6 by 6 inches, paper, 3.90 rm. The various methods of welding by gas, thermite, and electricity are described, including auxiliary equipment. Plans, calculations, and procedure for welding construction members are covered, as well as other special applications.

Die HOCHSPANNUNGSPREILEITUNGEN. By K. Girkmann and R. Königshofer. Vienna, Julius Springer, 1938. 504 pages, illustrated, 10 by 7 inches, cloth, 46.80 rm. An account of high-voltage overhead transmission lines, in which the structural and the electrical problems both receive treatment. Design and construction, route location, erection, and maintenance are discussed in detail.

(The) J. & P. SWITCHGEAR BOOK. By R. T. Lythall. (Third edition). London, Johnson & Phillips, Ltd., Oct. 1938. 431 pages, illustrated, 9 by 6 inches, cloth, 10s. 6d.

This handbook for the user and operator is intended as an outline of modern switchgear practice. Subjects covered include descriptions of apparatus and instruments for both indoor and outdoor switchgear, bus bars and connections, protective gear, and various problems connected with the selection, operation, and maintenance of switchgear installations.

PROBLEMS in PUBLIC UTILITY ECONOMICS and MANAGEMENT. By C. O. Ruggles. (Second edition). New York and London, McGraw-Hill Book Co., 1938. 772 pages, illustrated, 9½ by 6 inches, cloth, $6.00. Problems that arise in public utility management are presented for analysis and illustrated by actual cases. Questions considered include the economic characteristics of public utilities; their production problems; management, organization, and finance; wholesale marketing of service; retail marketing; valuation, rate making, and fair return; and regulation and management.

THEORETICAL MECHANICS, a Vectorial Treatment. By C. J. Coe. New York, Macmillan Co., 1938. 555 pages, illustrated, 9 by 6 inches, cloth, $5.00. The basic principles of vector analysis are explained and applied to classical mechanics, and through it to mathematical physics.

(The) RADIO AMATEUR'S HANDBOOK (16th Edition). 1939, by the American Radio Relay League, West Hartford, Conn. 560 pages, illustrated, 11 by 7 inches, paper, $1.00. This manual covers the amateur short-wave field. The fundamental principles and the design, construction, and operation of transmitting and receiving apparatus are described.

(The) RADIO MANUAL. By G. E. Sterling. (Third edition.) New York, D. Van Nostrand Co., 1938. 1,120 pages, illustrated, 8 by 5 inches, leather, $6.00. A textbook for those entering the radio profession as engineers, inspectors, and operators, and a reference book for those so engaged. An account of electrical fundamentals is given, together with information on equipment and systems, methods of measurement, and the rules and regulations governing radio operation.

SERVICE CHARGES in GAS and ELECTRIC RATES. By H. F. Havlik. New York, Columbia University Press, 1938. 234 pages, tables, 9 by 6 inches, cloth, $2.75. A study of the theory and practice of gas and electric rate-making, specifically concerned with the problem of service charges.

WELDING ENCYCLOPEDIA, 1938, compiled and edited by L. B. Mackenzie and H. S. Card. (Ninth edition.) Chicago, Welding Engineer Publishing Co., 696 pages, illustrated, 9 by 6 inches, leather, $5.00. Principal topics covered include the main types of welding, the most important fields of use, metals and alloys, metal spraying, rules, codes and specifications, tables and charts of engineering data, testing methods, and operator training. Company names are included with a listing of the trade names of their products.

CLAUS KRÖNCKE als Beispiel der Ingenieurausbuildung gegen Ende des 18. Jahrhunderts im Gegensatz zur heutigen Berufsausbildung des Bauingenieurs. By W. Sbrzesny. Berlin, VDI-Verlag, 1938. 46 pages, 8 by 6 inches, paper, 250 rm. An account of the life of a nineteenth-century engineer in which special attention is given to his education for the profession; the pamphlet contributes to the history of engineering education.

DANIEL WILLARD RIDES the LINE, the Story of a Great Railroad Man. By E. Hungerford. New York, G. P. Putnam's Sons, 1938. 301 pages, illustrated, 9 by 6 inches, cloth, $3.50. Engine driver, superintendent, vice-president, president: This is the story of a man who not only left the impress of his personality on every railroad with which he was connected but also played an important part in the general railroad and labor istuation of the United States.

DAVISON'S TEXTILE CATALOGUES and BUYER'S GUIDE (1938 edition). Ridgewood, N. J., Davison Publishing Co. 806 pages, illustrated, 12 by 9 inches, cloth, free to all textile manufacturing plants, $12.00 to others. Brief catalogs of manufacturers who serve the textile industry.

DIFFERENTIAL- und INTEGRALRECHNUNG, 3 volumes. (Göschens Lehrbücherei, Bd. 24, 25, and 26). By O. Haupt and G. Aumann. Berlin, Walter de Gruyter & Co., 1938. Illustrated, by 6 inches, cloth, volume 1, 196 pages, 1.20 rm.; volume 2, 168 pages, 9.80 rm.; volume 3, 183 pages, 10.60 rm. A discussion of series and real functions of one or more variables, the differential calculus of functions of one or more variables, and the theory and applications of integrals.

(An) ENGINEER'S MISCELLANY. By O. Bathe. Philadelphia, Patterson & White Co., 1938. 136 pages, illustrated, 11 by 8 inches, cloth, $4.00. Ten contributions to engineering history, illustrated by reproductions of photographs and contemporary prints.

THEORY of EQUATIONS. By J. M. Thomas. New York and London, McGraw-Hill Book Co. 1938. 211 pages, illustrated, 8 by 6 inches, cloth, $2.00. A textbook on the theory of algebraic equations for advanced undergraduate and graduate students. The treatment, though elementary, is in accord with "modern algebra."

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Papers Presented at Pacific Coast Convention, Portland, Ore., August 9–12, 1938

No.	Authors	Titles of Papers (Some Shortened)
☐ 38-43	Lightning Arrester Subcom.	*Testing and Application of Lightning Arresters
☐ 38-99	Monroe	†Electrification of the San Francisco-Oakland Bay Bridge Railway
☐ 38-100	Whelchel	*Trends in Electrical Equipment in Hydraulic Power Plants
☐ 38-101	McMillan	*Polarity Limits of the Sphere Gap
☐ 38-102	Smith	*Use of Bismuth Bridge Magnetic Fluxmeter for A-C Fields
☐ 38-103	Shuck	*A Variable-Register-Ratio Watt-Hour Meter
☐ 38-104	Thomson	*Similitude of Critical Conditions in Ferroresonant Circuits
☐ 38-105	Morris	*Application of Copper-Oxide Rectifiers
☐ 38-106	Wagner	*Self-Excitation of Induction Motors
☐ 38-107	Ager	*Determination of Induction-Motor Performance
☐ 38-108	Dalziel	*Static Power Limits of Synchronous Machines
☐ 38-109	Peterson	General Operation of Transmission Line
☐ 38-110	Cozzens & Peterson	Corona Experience on Transmission Line
☐ 38-111	Cozzens	Insulation and Lightning Protection
☐ 38-112	Laughin	Carrier-Current Equipment
☐ 38-113	Draper	Transmission-Line Relay Protection
☐ 38-114	Skellett	Narrow-Band Transmission System for Animated Line Images
☐ 38-115	Norwine	*Controlling Amplitude Characteristics of Telephone Signals
☐ 38-116	Gaylord	*The Pumping System of the Colorado River Aqueduct
☐ 38-117	Skilling	The Electrical Strength of Air at High Pressure
☐ 38-118	Pierce and Hamilton	*Phase-Angle Control of System Interconnections
☐ 38-119	Lyon	*The Electrostatic Unbalance of Transmission Lines

Papers Presented at Southern District Meeting, Miami, Fla., November 28–30, 1938

☐ 38-121	Kuhn	Electrolysis and Corrosion of Underground Metallic Structures
☐ 38-123	Evans	Lightning Protection Improvements for Transmission Lines
☐ 38-124	Kirkwood	Grading the Engineer's Job
☐ 38-125	Almond	Electrical Design of Pickwick Landing Project
☐ 38-126	Jones	Multifyre System for Extinguishing Oil Fires
☐ 38-127	Housley	Reconditioning of Insulating Oils by Activated Alumina
☐ 38-128	Stratton & Stratton	Shop Practice in the Repair of High-Voltage Bushings
☐ 38-129	George & Bessesen	Generator Damper Windings at Wilson Dam

Papers Presented at Winter Convention, New York, N. Y., January 23–27, 1939

☐ 38-122	Putman & Dann	Loading Transformers by Copper Temperature
☐ 39-4	Morgan, Brown & Schumer	Determination of Stray Load Loss in Induction Machines
☐ 39-5	Potter	Measurement of Temperature in Squirrel-Cage Induction Motors
☐ 39-6	Hellmund	The Rating of Electrical Machinery and Apparatus
☐ 39-8	Brown & Cahoon	An Amplifier-Wattmeter for Measurement of Watts and Vars
☐ 39-11	McDonald	Voltage Control of Mercury-Arc Rectifiers
☐ 39-13	Johnson	Predetermination of Temperatures in Resistance Welds
☐ 39-15	Relay Subcommittee	High-Speed Relaying Experience and Practise
☐ 39-17	Lynn	Effects of Temperature on Rotating Electrical Machinery
☐ 39-18	Rutherford	The Rating and Application of Motors for Refrigeration
☐ 39-19	AIEE & EEI Committees	Bus Protection
☐ 39-21	Konn & Craton	Performance of the 3600-Hp New Haven Electric Locomotives
☐ 39-22	Kotterman	The Magnesium Copper Sulphide Rectifier Battery Charger
☐ 39-23	Seletzky & Zucker	Sensitivity of the Four-Arm Bridge
☐ 39-24	DeBellis	Modernization of Switch House Design
☐ 39-26	Strang & Hanna	Modernization of Switch House Design
☐ 39-27	Harder	Relay Protection of Pennsylvania Railroad Electrification
☐ 39-28	Carruthers	Copper-Oxide Modulators in Carrier Telephone Systems
☐ 39-31	Smith, Sonnemann & Dodds	Applying Ratio Differential Relays for Bus Protection
☐ 39-32	Stitcher & Thomas	Effect of Corona Discharge on Liquid Dielectrics
☐ 39-33	Kent & Blye	Inductive Co-ordination With Series Sodium Lighting Circuits
☐ 39-34	Ludwig & Grissinger	A New High-Capacity Air Circuit Breaker
☐ 39-35	Dickinson	"De-Ion" Air Circuit Breaker for Central-Station Service
☐ 39-36	MacNeill & Hill	Multiple-Grid Breakers for High-Voltage Service
☐ 39-39	Cox & Jones	Ignitrons for the Transportation Industry
☐ 39-40	Gray & Breyer	An Electronic Control Circuit for Resistance Welders
☐ 39-41	Ingram	Cold-Cathode Gas-Filled Tubes as Circuit Elements
☐ 39-42	Cassidy & Mosteller	Continuous Processing for Automobile Tire Fabrics
☐ 39-43	Smith	Electric Drives for Supercalenders in Paper Mills
☐ 39-45	Chu & Barrow	Electromagnetic Horn Design
☐ 39-46	Byrne	Polyphase Broadcasting
☐ 39-47	Dellinger	The Role of the Ionosphere in Radio Wave Propagation
☐ 39-49	Peterson	Power System Voltage Recovery Characteristics
☐ 39-52	Clarke, Crary & Peterson	Overvoltages During Power System Faults
☐ 39-53	Kendall & Affel	A 12-Channel Carrier Telephone System for Open-Wire Lines
☐ 39-54	Lawton	The Submarine Cable Plow
☐ 39-55	Nelson	The Submarine Cable Depthometer
☐ 39-56	Sorber & Smith	Remote Control Tollboard
☐ 39-57	Scudder & Reynolds	Crossbar Dial Telephone Switching System
☐ 39-58	Corney & Edson	Modernization of L Street Station Switch House
☐ 39-59	Hildebrand	Duty Cycles and Motor Rating
☐ 39-65	Roby	Simplified Precision Resistance Welder Control
☐ 39-66	Wright	Power Supply for Single-Phase Resistance Welders
☐ 39-67	Holslag	The A-C Arc Progresses
☐ 39-68	Kidder	Notes on Emergency Ratings
☐ 39-69	Thomas	Economical Loading of Underground High-Voltage Cables
☐ 39-71	Shanklin	Low Gas Pressure Cable
☐ 39-72	Lincoln & Sprole	Demand Meter Time Periods
☐ 39-73	Keinath	An Automatic A-C Potentiometer and Applications to Testing
☐ 39-74	Green	Aluminum-Nickel-Cobalt Brake Magnets for Watt-Hour Meters

* These papers have been published in the Transactions section of Electrical Engineering.
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Transactions

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Phase-Angle Control of System Interconnections

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Synopsis: This paper describes an application of a new method of automatic control between two interconnected power systems, whereby greater utilization of the interconnection capacity is secured. As the stable limit of the interchange between systems is affected by variations in the magnitude and location of intermediate loads on the respective systems, direct control of the phase angle between systems recognizes such variations and permits a flexible and more stable type of operation including, when desired, maximum transfers of energy. An indication of the 60-cycle voltage from a desired point on one system is continuously transmitted by means of carrier current, to a point on the second system where its phase position is compared with that of the 60-cycle voltage at the receiving point. The output of generating units at the control station is automatically regulated to maintain the phase angle between systems at desired values or within predetermined limits.

THE power systems in the Pacific Northwest have been successfully operated interconnected for many years. In addition to the normal or routine functions, on several occasions these interconnections have been called upon to transfer large blocks of power and energy to alleviate abnormal conditions on one system or another, averting serious power shortages.

Heretofore, the control of the power flow between these systems has been accomplished principally by manual operation. The amount of power which has been interchanged, under some conditions, and between some of the systems, has not approached the stable limit of the interconnections, and manual control has not been difficult. On some of these interconnections, however, experience has demonstrated, as in similar situations in other parts of the country, that because of the time required for communication and manual control of generating units, the interchange had to be regulated to values well within the stable limits, in order to prevent, or at least limit the number of severe disturbances otherwise occasioned by the systems separating due to relay action as stable limits were approached, or actually pulling out of step.

In considering the application of automatic-control equipment for the interconnection between the systems of The Montana Power Company and The Washington Water Power Company, so that a flow of power closer to the stable limit could be safely carried, a new method of control, based upon the phase-angle difference between systems, was conceived and developed. This paper describes the application and the experience so far obtained with this type of control.

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Description of Systems and Interconnection

Figure 1 is a map of the Northwest showing the principal transmission lines of the several interconnected systems.

On The Montana Power Company there is approximately 300,000 kw of hydroelectric generating capacity with 250,000 kw usually in service. The total capacity will be increased to 350,000 kw in 1938. A large part of this generating capacity, and a substantial part of the load served, are both located in the Great Falls area. Many of the larger individual loads served from this system, including hoists, railway, and dredge loads, are of such magnitude and fluctuating character that sudden load changes of from 5,000 to 30,000 kw are not uncommon.

The point of interconnection between The Montana Power Company and The Washington Water Power Company systems is at Burke, Idaho. For a number of years previous, and at the time this application of automatic control was planned, the ability to interchange power between these two systems was limited by the single 110-kv, 170-mile transmission line of the Chicago, Milwaukee, St. Paul and Pacific Railroad Company between East Portal and Gold Creek. The capacity for power flow eastward was variable, depending upon seasonal variations in the Thompson Falls hydroelectric plant output. The second line from Thompson Falls, via Flathead to Anaconda, was added in March 1937, practically coinciding with the installation of the phase-angle control equipment. The purpose of this latter transmission line was to transmit power into Montana during an unprecedented low-water period and to furnish a second channel for Thompson Falls power into the Montana system as well as that from Flathead. At later periods it is contemplated these lines may transmit power to the west.

The Washington Water Power Company system is also served by hydroelectric generation, with approximately 200,000 kw of capacity, most of which is usually in service. A large concentration of capacity and load on this system is in the Spokane area.

The Washington Water Power Company system is in turn interconnected with the system of the Puget Sound Power and Light Company on the west, having approximately 300,000 kw of capacity. To the southwest, Washington is interconnected with the Pacific Power and Light and Northwestern Electric Companies, having an aggregate capacity of 120,000 kw. The Portland General Electric Company, 175,000-kw capacity, and Washington Gas and Electric Company, 30,000-kw capacity, are in turn interconnected with the Northwestern Electric Company system in the Portland area. The Portland General Electric Company, however, is not normally

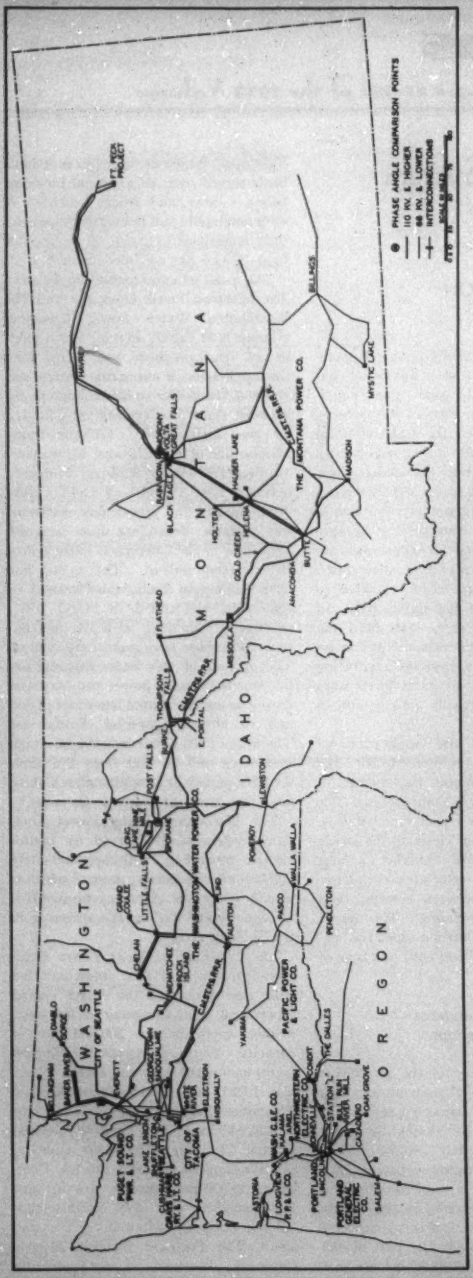


Figure 1. Major electric power systems—Pacific Northwest

operated in parallel with the Northwestern Electric Company when Northwestern is in parallel with other systems in Washington and Montana.

For several years the Long Lake hydroelectric station of The Washington Water Power Company has served as the primary frequency-controlling station for the entire group of systems. Additional frequency-control equipments have been available at the Morony station in Montana and the Ariel station in the Portland area, but have not generally been used when operating interconnected with Washington.

Operating Limitations With Manual Control of Interchange

From previous operating experience, when transmitting power from Washington to Montana over the original connection, it was known that the systems were likely to pull out of step whenever the power input into the line at East Portal (interchange at Burke, plus Thompson Falls generation, less local load at Burke and line loss) reached values in excess of 50,000 kw. The normal practical operating limit, under manual control procedure, was considerably less, in the order of 40,000-kw maximum, or 35,000-kw average, because whenever attempting to operate at any higher value, the rapid "drifting" of the power flow would reach the pull-out point too often. The usual "swings" in power over this interconnection were approximately 5,000 kw, with occasional swings of up to 15,000 kw.

With the Thompson Falls plant output (40,000-kw maximum during high-water months and 20,000-kw average during low-water months) flowing eastward, the maximum permissible average power flow through Burke, Idaho, ranged from approximately 0 to 15,000 kw. To obtain these average flows, with manual control, it was necessary to place observers at Burke and Gold Creek; the observer at Burke giving very close attention to the meters and promptly reporting excessive loading conditions to the observer at Gold Creek, who would in turn report conditions to the controlling station. Even with these precautions, from one to eight system separations would occur practically each day.

Because of a combination of circumstances, including several successive years of lower-than-normal precipitation and run-off in Montana, it was decided in the fall of 1935 that the capacity of the interconnection would have to be increased and at the same time maximum possible use might have to be made of this interconnection in transferring energy into Montana during the succeeding one or two years. It was decided to build the second transmission line, referred to above, and install automatic control equipment, in order to increase the practical operating limit and the load factor of the interconnection.

Experimental Tie-Line Load Control

As a preliminary step, an experimental installation was made of automatic tie-line load control, based upon a measurement of the power flow in the 110-kv line at Gold Creek. A carrier-current-telemetering circuit, operating at 20 kilocycles over the private open-wire telephone line, with variable frequency

modulation, gave an indication at the Morony hydroelectric plant of The Montana Power Company on the Missouri River near Great Falls, Montana, of the power flow in the line at Gold Creek. The automatic-frequency controller installed at the Morony plant was temporarily modified and used for automatic tie-line load control. This type of automatic control gave a definite improvement in the interchange capacity; the permissible average flow through Burke being increased to approximately 21,000 kw, with separations of the systems occurring on the average of only once every two days.

Conception and Development of Phase-Angle Control

In considering the alternate locations for a permanent installation of a tie-line load measurement and telemetering transmitter, it was recognized that no one location could be chosen where the tie-line load as such could be controlled to any definite quantity over a period of time, and at the same time secure the maximum possible transfer of energy between systems. With only the Chicago, Milwaukee, St. Paul and Pacific Railroad Company line constituting the tie between systems, the power transfer at any point varied considerably due to the nature of the railway load. Not only did the railroad's electric trains have a widely variable demand, but the location of the load along the transmission line varied as the trains progressed from one section to another. Furthermore, these trains employed regenerative braking so that at times, either a part or all of the load actually became generation with a correspondingly variable point of application. This was particularly true along the 110-kv line from East Portal to Gold Creek.

For example, if the tie-line load at Gold Creek were to be controlled, the permissible power flow at this point would be greater when the intermediate-substation loads were light, especially at the Gold Creek end of the line, than when the intermediate loads were heavy. Consequently the control would have to be set for the smaller value of power transfer, to be safely within the stable limit under all conditions, and no advantage could be taken of the greater permissible flow during a large proportion of the time.

Likewise, if controlling the tie-line load at East Portal, for example, the control would have to limit the flow at this point to the amount that could safely be carried when the intermediate loads between East Portal and Gold Creek were light, without taking advantage of the greater permissible flow whenever a large part of the power flowing past this point was being consumed at the East Portal, or other substations near the western end of the line.

It was also recognized that with the planned addition of the Thompson Falls-Flathead-Anaconda circuit, stability limits, division of power flow between circuits, and permissible angular displacements between the systems would change.

Inasmuch as stability is basically a function of angular displacement between systems, it was conceived by the authors that the phase angle itself should be utilized for the control of the interchange, rather than a measurement of the power flow at any one point. It was proposed to transmit, by a continuously modulated carrier-current signal over the transmission circuits, an indication of the 60-cycle bus voltage at a point on the Washington system to a point on the Montana system. The received signal, being an indication of the angular position of the voltage in Washington, would be compared with the phase position of the local Montana 60-cycle bus voltage.

Based on a measurement of the phase-angle difference between these two voltages, the output of generating units at the control station selected would be automatically regulated to maintain the phase angle at the desired point or within predetermined limits.

It was thought that phase-angle control might provide several alternate methods of operation, including those shown in figure 2.

Development and application of this method of control involved consideration of the following questions of fundamental importance:

What location should be chosen on each system, for voltage measurement in the determination of the proper phase angle for control?

What phase-angle distortion or attenuation would occur in the carrier-current equipment and transmission channels, from the transmitter input to the receiver output, and what variations would there be in this transmission under different operating conditions?

What would be the effects of outages of lines at any point on the network between the two phase-angle determination points?

Following co-operative studies with engineers of Leeds and Northrup Company and Westinghouse Electric and Manufacturing Company, it was concluded that:

1. The phase angle should be measured between the East Side substation, near Spokane, on the Washington system, and the Morony hydroelectric station, near Great Falls, on the Montana system. For practically all operating conditions these locations would be most representative of the hearts of the systems, and this phase-angle comparison, therefore, a better measure of stability between the two systems. It appeared to have the further advantages of (*a*) immediately recognizing an outage of any line having an appreciable effect on the interconnection capacity, such as on the parallel lines between Spokane and Burke, or between Butte and Morony; (*b*) the receiver would be located directly at the station best suited for control purposes, due to the storage capacity, large and efficient units, and short penstocks, obviating the necessity for an additional telemetering circuit or a long-distance control circuit to the control station; and (*c*) the carrier-current equipment would be located at points well suited for adequate maintenance.

A. With the predetermined limits of phase angle within a narrow range of large positive (or negative) values, resulting in operation close to the stable limit with maximum permissible power flow in one direction (or the opposite)

B. With the predetermined limits of phase angle within a narrow range between a small positive value and a small negative value, or wherever required, to result in a minimum average power flow between the systems, with maximum stability, and maximum ability of each system to help the other under emergencies

C. With the predetermined limits over a wide range between a large positive value and a large negative value, resulting in the least amount of control or definite scheduling of the amount of power flowing between systems, except as the stable limit was approached in either direction

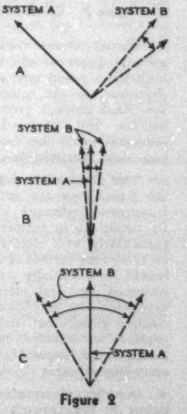


Figure 2

Figure 3. Carrier-current transmitter

2. Carrier-current transmitting and receiving equipment could be designed and built which would have an over-all shift or distortion, in the equipment itself, of a very small amount, probably less than five degrees, and that whatever distortion occurred would be essentially constant, and could therefore be corrected for.

3. The phase-angle shift or distortion of the signal over the entire carrier-current transmission channel might be affected by variations in temperature or weather, particularly with sleet for example; however, for long periods of time the distortion should be essentially constant and easily corrected for, and after some operating experience with the equipment, such gradual changes as occurred with changes in temperature or weather could probably be anticipated or followed fairly closely without materially affecting the degree of control.

4. One effect of outages of lines at different points in the network between the two phase-angle determination points would be to increase the net or effective impedance of the tie, and decrease the permissible power transfer between systems. In this respect automatic control based on phase angle should inherently recognize such line outages and compensate for them in correcting the interchange to values of the same relative degree of safety, with respect to stable limits.

Another effect of an outage of an intermediate line might be to change the phase-angle distortion or attentuation in the carrier-current measuring channel. As it was not planned to confine the carrier transmission to a single channel, it was believed that the loss of one of several parallel paths in the carrier channel would not seriously affect the practical operation of the control.

5. Phase-angle control equipment could readily be developed, and installed at the Morony hydroelectric station in Montana, having a generating capacity of 45,000 kw in two units, using as a basis the already-developed phase-difference recorder,* which, together with the frequency-control equipment already installed, would provide the following alternate methods of control:

Flat Phase-Angle Control. For controlling the phase angle to a predetermined value, or within predetermined limits, independent of frequency.

Phase-Angle Bias Control. For control primarily to a definite predetermined value of phase angle, but with assistance given for short periods in the control of system frequency.

Selective-Frequency Control. For controlling to a constant value of system frequency, but only when in so doing, the correction would also assist in controlling the phase angle to a predetermined value.

Flat-Frequency Control. For use as in the past, with isolated operation of the system.

It was decided to proceed with the development and installation of the equipment, and the complete phase-angle control system was placed in service in December 1936.

The control equipment as installed provides for any of the four types of control described under conclusion 5, and the locations of the phase-angle determination points and control equipment were in accordance with the other conclusions outlined.

The predetermined basic phase-angle difference for control is fully adjustable to any angle (0 to 360 degrees), but the width of band around this base reference control point is adjustable up to plus or minus 30 degrees.

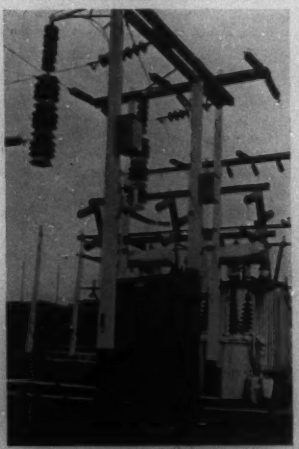


Figure 4. Transmitter installation at East Side substation, Spokane, Wash.

With reference to the three alternate methods of interconnected operation previously described in figure 2, and designated as *A*, *B*, or *C*, which were conceived as possible with this type of control, the equipment as installed, therefore, has sufficient flexibility for method *A* (maximum interchange in either direction); and method *B* (maximum stability or minimum interchange), but method *C* (minimum control or scheduling) is applicable only within the range of plus 30 degrees to minus 30 degrees.

Description of Carrier-Current Equipment

The carrier-current equipment was manufactured by Westinghouse Electric and Manufacturing Company and consists of:

1. A transmitter, surge protective equipment, and coupling capacitors, located at the East Side substation in Spokane, on The Washington Water Power Company system.

2. A receiver, surge protective equipment, and coupling capacitors, located at the Morony hydroelectric station, near Great Falls, on The Montana Power Company system.

The distance between the transmitter and the receiver, by transmission circuits, is approximately 460 miles. Coupling is between one phase wire and ground. No wave traps were installed at any point, so that the carrier-current signal is permitted to flow over the entire 110-kv network of the group of interconnected systems.

The carrier-current transmitter, shown in figures 3 and 4, has a frequency range of 50 to 150 kilocycles and is rated 150-watts modulated output. The oscillator is of the Colpitts type, followed by one stage of class *A* and one stage of push-pull class *B* amplification. The circuit is plate-modulated, using a single transformer, with excitation from a potential transformer connected to the East Side substation 110-kv 60-cycle bus. The outdoor steel cabinet houses the tuning inductance as well as the transmitter proper.

The carrier-current receiver, shown in figure 5 is of simple design, and consists

*"Voltage Regulation and Load Control," H. C. Forbes and H. R. Searing, AIEE TRANSACTIONS, 1934, pages 903–09.

of a detector and two stages of resistance-coupled amplification. The receiver delivers one-watt output. Two tuning controls are used, one for input and another for grid tuning. Meters are provided for indications of filament voltage, and final output plate current. The receiver is housed in an outdoor steel cabinet together with its tuning inductance. All the receiver components are mounted on one panel in this cabinet and can be readily removed.

The surge protective equipment at each location consists of a 7,500-volt Deion fuse, two enclosed gaps, and one drain coil, all equipped for outdoor mounting.

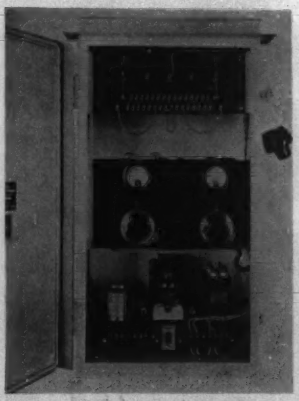


Figure 5. Carrier-current receiver

The line coupling capacitors at each location consist of three suspension-type units connected in series with an over-all capacity of 0.00133 microfarad.

Since the accuracy of this equipment depends upon the constancy of the phase-angle difference between the transmitter modulating voltage and the receiver-output voltage, careful consideration was given in the design to limit this phase difference and to minimize variations thereof. The completed equipment was checked to determine the magnitude and variations in this angle, by means of a cathode-ray oscillograph, but the angle was found to be so small that it could not be accurately measured in this manner. For all practical purposes in this application, the shift in phase angle in the carrier equipment itself was considered to be of negligible magnitude.

Another feature of this equipment, while not a new engineering development nor confined exclusively to this set, is the use of iron-cored transformers for carrier frequencies of 50 to 150 kilocycles. By giving special consideration to leakage reactance and distributed winding capacities, efficiencies have been secured at 150 kilocycles that are comparable with commercial 60-cycle transformers.

Description of Automatic-Control Equipment

The fundamental control equipment for phase-angle, frequency, and load control was manufactured by Leeds and Northrup Company; auxiliary switchboard equipment by Westinghouse Electric and Manufacturing Company. The complete control equipment as installed at Morony hydroelectric station includes the following major items:

1. Manually operated phase shifter
2. Phase-angle recorder controller with automatic-droop corrector
3. Frequency controller
4. Proportionate load controller
5. Frequency recorder

These various items perform the following functions in the complete control system.

The manually operated phase shifter is connected in the potential circuit from the Morony bus, and is used to shift this reference voltage by the number of degrees desired to be maintained between the two systems. The controller will maintain this difference by controlling to zero degrees on the phase-angle recorder-controller. Theoretically the phase shifter also may be considered available to correct or compensate for any phase-angle shift occurring in the carrier-current transmission of the remote reference voltage, but in practice this step is unnecessary and the over-all apparent phase-angle difference is used.

As its name implies, the phase-angle recorder-controller produces a graphic record of the relative phase angle of the local Morony bus voltage (as corrected by the phase shifter), with respect to the reference voltage (the received indication of the Spokane bus voltage). Deflection to the left of the center of the chart indicates Morony voltage (as corrected) lagging with respect to Spokane. In effect, therefore, this instrument gives a micrometer reading of the algebraic difference between the phase-shifter setting and the apparent phase-angle difference between the bus voltages. The recorder has a range of plus and minus 30 degrees which is more than ample to cover the normal variations from the base setting. This record on the ten-inch chart gives a very open scale and permits direct readings to one degree of phase-angle difference.

The measuring circuit of the phase-angle recorder is shown schematically in figure 6, and is basically a form of a-c potentiometer which employs the null method of measuring the angle between the two sources, shown connected to $E1$ and $E2$. If these voltages are exactly in phase, the recorder galvanometer will balance when the pen and indicating pointer are exactly in the center of the scale. If the voltage of the Morony bus, as corrected by the phase shifter, lags or leads the reference bus voltage (the received indication of the Spokane voltage), in time phase, a current will flow through the galvanometer, causing the "micro-max" balancing mechanism to change the relative values of capacity and resistance in the measuring circuit until zero deflection of the galvanometer is obtained. The recording pen and the indicating pointer move as a unit with the balancing mechanism to show the new phase-angle difference.

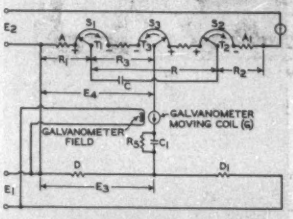


Figure 6. Measuring circuit on the phase-angle recorder-controller

Besides measuring and producing a graphic record of the phase-angle difference, this instrument contains the necessary contacts and control slidewires for originating correcting impulses which are sent to the governor motors to vary the Morony generation as required to maintain the desired phase angle. A unique feature of this control is an automatic-droop corrector which varies the rate at which the controller restores the phase-angle departures back to schedule. If the phase-angle trend is away from the control point, a proportionately larger correction is made than when the trend is toward the control point. In other words, the control action is a function of both magnitude of deviation and trend of the deviation from schedule. This prevents the tendency for the control to "hunt," or "overshoot" and was found

to be an essential feature for this application.

The frequency controller is of the standard proportional-step type. When the Montana system is operating alone, this instrument is used to maintain the frequency. It is also used in connection with the phase-angle recorder to provide a bias of phase angle on the frequency for certain operating conditions.

Figure 7. Switchboard control panels at Morony hydroelectric station

The proportionate-load controller is of a similar type and is used to divide the load swing with the second unit, regardless of the type of control on the station.

Contacts were added to the frequency recorder to trip the control when the system frequency departs a predetermined amount from normal, such as under fault or surge conditions.

With this equipment the following four alternate types of control, which were previously described, are available:

1. Flat phase-angle control
2. Phase-angle bias control
3. Selective-frequency control
4. Flat-frequency control

The change from one type of automatic operation to another is accomplished by a single station operation selector switch on the automatic-control panel. The appearance of this panel is shown in figure 7. Figure 8 shows the appearance in greater detail of the phase-angle recorder-controller itself.

Operating Experience

The complete phase-angle control equipment was first placed in service on December 10, 1936. The phase-angle recorder-controller instrument initially installed was found to have an inadequate speed of response, as the changes in phase angle occurred much more rapidly than had been anticipated. The original instrument was replaced in July 1937, with one having approximately six times the rate of control response. The operation of the control equipment has been very satisfactory and it has not required any maintenance other than oiling and cleaning.

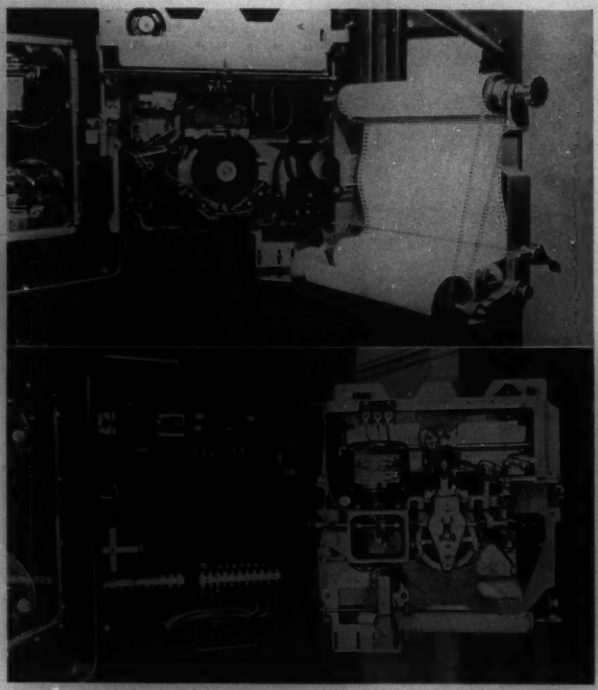


Figure 8. Views of the phase-angle recorder-controller

Operation of the carrier-current equipment has also been very satisfactory. The equipment was originally installed with coupling to two phases of the 110-kv system, but transmission tests indicated superior performance with coupling between one phase and ground within the frequency band desired, and operation has been on this basis. It is very seldom that a signal failure occurs due to storm conditions. While not provided in the original installation, an automatic alarm has since been added for signaling the attendant in the event of failure of the carrier-current signal. This consists of an electronic relay with the grid of the tube controlled positive by the incoming signal. On the failure of this signal, the tube stops drawing current and releases a relay, tripping off the automatic controller and operating an alarm. Maintenance of the carrier-current equipment has consisted principally of tube replacements. Both the transmitter and receiver have been modified in order to use standard tubes.

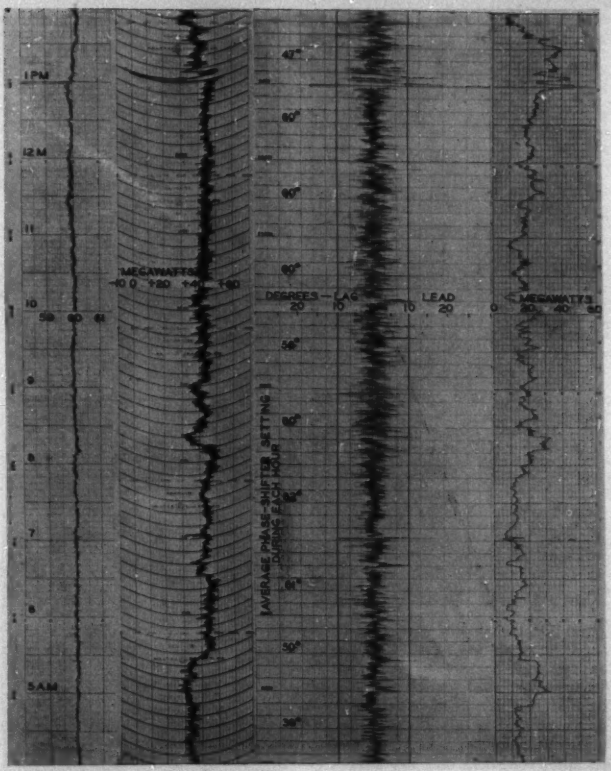
Previous a-c calculating board studies indicated that when the new line was completed, a phase angle of approximately 72 degrees between Spokane and Morony would be the "practical steady-state limit," with a corresponding total power flow eastward, consisting of the

interchange at Burke plus the Thompson Falls generation, of 75,000 kw, for the particular distribution of the intermediate loads assumed. This "practical steady-state limit" was the maximum power flow or phase angle possible, consistent with maintaining the minimum allowable operating voltages at substations along the line. The theoretical steady-state power limit would be slightly higher, but was not determined in those studies. It was thought that in actual operation, the average amount of power delivered, and the phase angle to be maintained, would have to be limited to values less than the above, to allow for power swings between systems, or to approximately 65,000 kw average and 60 degrees.

Experience with the new line and the phase-angle control equipment in service has shown that when operating with an average indicated phase angle between systems of 55 degrees, the only separations of the systems are those resulting from line troubles. At 60 degrees, separations are likely to occur about once every three days (from operation of an instantaneous undervoltage relay at Burke indicating instability). At 70 degrees, operation is only possible with continuous vigilance on the part of the operators. The maximum indicated phase angle at which the systems have been operated under automatic phase-angle control, was 74 degrees, and under the system loading conditions existing at the time the total power flow eastward was 61,000 kw.

The total hourly average power flow eastward, however, has often reached 80,000 kw, the maximum recorded being 82,700 kw. For this large hourly average, the flow during the hour varied from 80,000 kw to 86,000 kw. The corresponding average phase-angle indication was approximately 55 degrees. Usually, however, an indicated phase angle of 60 degrees results in a power flow of from 50,000 kw to 60,000 kw.

Figure 9 illustrates the typical performance of the interconnection under automatic phase-angle control. In this figure, the first chart at the left is the system frequency, the second chart is a record of the power interchange at Burke (from 40,000 to 60,000 kw toward Montana), the third chart shows the variations in the phase-angle difference between systems, and the chart at the right gives the record of the Morony plant output. It may be clearly noticed that over considerable periods of time, while the average phase angle remained essentially constant, the average kilowatt



A System frequency B Burke interchange C Phase-angle difference D Morony output

Figure 9. Typical charts showing operation of interconnection under phase-angle control

interchange between systems was continually varying several thousand kilowatts with occasional changes of as much as 6,000 to 10,000 kw. This illustrates the fundamental idea of phase-angle control as contrasted to tie-line load control. Such changes in interchange indicate the normal variations in the location and magnitude of the intermediate loads on the two systems, and are to be expected and desired under this type of control. Also illustrated in figure 9, at about 1 p.m., is an instance of the systems separating unexpectedly, which is never desired. In this instance the apparent phase angle between systems reached a value of 76 degrees and the interchange at Burke 55,000 kw when the interconnection was opened by operation of overload relays.

Figure 10 illustrates in greater detail the typical comparative phase-angle variations (*a*) when the automatic controller is out of service and with the Morony output regulated manually to maintain constant phase angle, and (*b*) with the automatic phase-angle control equipment in service. Whenever the Morony output gets outside of the regulating range of the generators in service, the phase angle, of course, cannot be held at the desired value. Such an occurrence is illustrated on this chart between 8 a.m. and 9 a.m.

Usual practice so far has been to operate with "phase-angle bias control," with frequency as the major influence. It is expected that further operating experience, not only with "phase-angle bias control," with varying relative degrees of influence between frequency and phase angle, but with "flat phase-

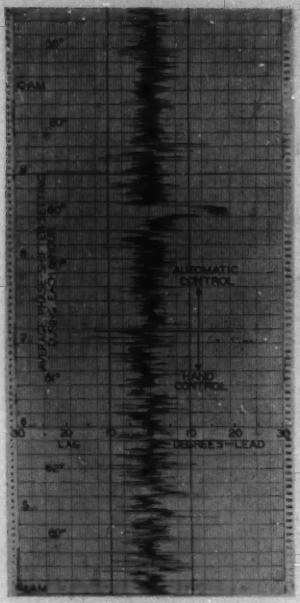
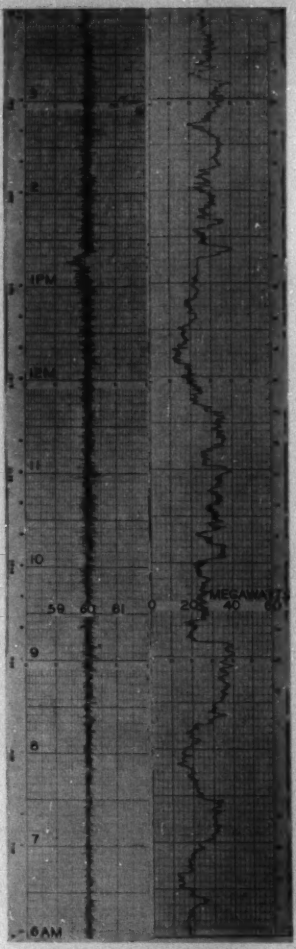


Figure 10. Typical chart—phase-angle difference—manual and automatic control

angle control" and "selective-frequency control," will permit more definite conclusions regarding the relative merits of different types of control for the different operating conditions that may arise.

Figure 11 shows typical charts of system frequency and Morony plant output, when the Montana system is operating isolated from the other systems, with automatic-frequency control in service at Morony. A comparison of the frequency record with that shown in figure 9 is of interest and of significance. The wider band of the frequency record in figure 11 is evidence of the relatively larger load changes with respect to the generating capacity, on the Montana system, as compared to the entire interconnected group of systems.

One of the difficult features in the control problem of this interconnection is the rapid power fluctuation as shown by the typical high-speed chart of power flow through Burke, figure 12. The governors and water wheels that are regulated by the phase-angle controller are not fast enough to eliminate these fluctuations, as tests have shown that the output of the generators does not respond to the control impulses for $4^1/_2$ to 5 seconds. While the controller helps to lessen the



Montana system frequency — Morony output

Figure 11. Typical charts illustrating isolated operation of Montana system with automatic frequency control

magnitude of the surges, it is obvious that any slow response of the governor, gate mechanism, and water column tends to lead away from the desired results. Further attempts are being made to secure faster action of the governor, thereby reducing the delay between control impulses and water-wheel response.

A co-operative study was made to determine the cause of these rapid and persistent surges in power flow through Burke by a committee made up of representatives from each of the interconnected companies. Material for the study was obtained in a unique manner which has many possibilities for further use. It being desired to secure simultaneous readings of power flow through interconnecting ties as well as readings of power output at several stations, each company planned to install high-speed

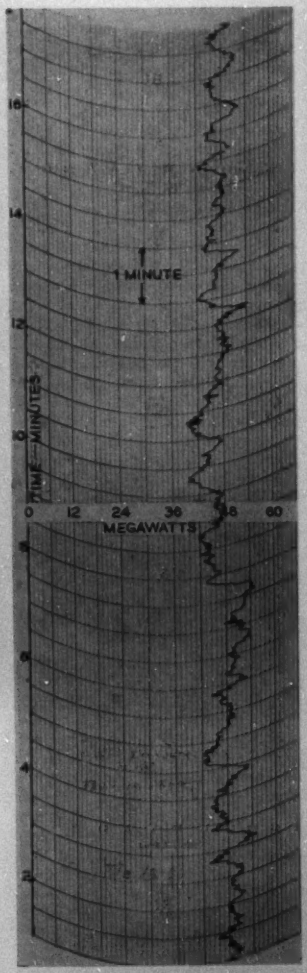


Figure 12. High-speed chart—megawatt interchange at Burke—power into Montana

wattmeters at key locations and one company would secure a high-speed frequency record.

In order to take numerous readings simultaneously, small homemade carrier-current receivers were installed at the location of each recording meter, with these receivers tuned to the phase-angle carrier frequency. In accordance with prearranged schedules, an observer at Spokane interrupted the carrier signal for a fraction of a second at regular intervals of 30 seconds. At each interruption the various observers marked their respective recording charts. In this manner simultaneous readings of power flow were taken on the systems of the Northwestern Electric Company, Puget Sound Power and Light Company, Pacific Power and Light Company, The Washington Water Power Company, and The Montana Power Company. As these charts indicated that five out of six times when the flow of power into Montana increased, the frequency was lower, indicating apparent power increases in Montana, and as it was not reasonable to believe that this proportion of the load changes occurred in Montana, further studies were made. It was concluded that many of the swings were not so much the direct result of actual load changes, as evidence of disproportionate and untimely increases in power input from certain systems and stations in endeavoring to restore system speed to normal—definitely indicating a lack of co-ordination of governors, both steam and hydraulic. If all governors had the same speed of response, the situation should be considerably better. This problem is still being studied co-operatively by the several companies.

Conclusions

Installation of automatic control based on phase angle has accomplished the following:

1. Made it possible more completely to utilize the capacity of the interconnection transmission facilities, practically up to the stable limit at all times, and thereby transfer greater amounts of energy. During one month, over 30,000,000 kilowatt-hours, an average of about 45,000 kw, or 70 per cent of the stable limit, were transferred.

2. Improved the operating performance of the interconnection by permitting large transfers of power without numerous separations of the systems. The average power flow possible with satisfactory performance is in the order of 20 to 25 per cent greater than that possible with manual control.

3. Relieved the operating personnel of much of the continuous and tedious supervision of the power interchange, decreased the number of telephone calls between operators and dispatchers, and minimized the manual operation of the controlling plant.

Discussion

V. M. Marquis (American Gas and Electric Service Corporation, New York, N. Y.): The paper by Messrs. Pierce and Hamilton describes another method of approach on the problem of regulating power flow between interconnected systems and is especially applicable where there are many intervening loads, the magnitude of which are of a highly fluctuating character. As interconnected systems have grown, it has become more and more apparent that merely tying together systems does not mean interconnected system operation unless the technique of operating these interconnections is properly developed. Great strides have been made over the past few years in developing this technique and there still remains work to be done.

On most large interconnected systems it has become apparent that to regulate properly the power flow between systems and thus maintain schedules manual control alone is not in general satisfactory. Some form of automatic control is usually necessary. For the most part it has been possible to work out a combination of frequency and tie-line control by simply using an indication of the power flow on tie lines either at the point at which the regulating is done or by telemetering from the proper point on the tie line.

The problem which the authors of this paper had to meet is somewhat more difficult due to the limitations in capacity of the lines and due to the nature of the loads tapped off between the systems. The result obtained in this case is ample proof of the effectiveness of the control system described by the authors. Although this development may have rather limited application, it is gratifying to know that another tool has been developed for improving the operating technique of interconnected systems.

A. N. Geyer (Woodward Governor Company, Seattle, Wash.): It has been a pleasure to hear Mr. Pierce talk about this unique control arrangement, about which we have been hearing good reports at several other meetings here in the Northwest during the past year or so. It has been my privilege to study even more accurate charts representing its performance, these being high-speed charts taken like the one of figure 12 at about one inch per minute. When such charts are assembled as in figure 9, with time markings all coinciding, the record of the phase angle is seen to follow very closely the changes of power in the tie line. Likewise, a further comparison of the Morony output curve shows very definitely the extent to which these are in agreement or conflict.

For example, take a conspicuous increase in power flow toward Montana, and straight below we look for an upswing of Morony output, with whatever delay actually occurs. Since this is given in the paper as being often four or five seconds, it seems unfortunate that the telemetered indication of upswing, after being transmitted immediately for several hundred miles to the generating station, is there delayed like this in going the remaining few feet to get the needed response on the prime mover.

Regarding the later reference to the unco-ordinated action of various governors on the interconnected systems, this would seem very likely when remembering that a good many of these are early-day models, thus not representing a high-grade performance on a par with this other part of the equipment concerned in this new method of control. A direct showing of how such old governors often perform may be seen in those particular plants where the several units are in a line enabling an observer at one end and looking across them to see the relative movements, and as the speed changes in regular manner, the governor movements are seen not to be together, but even traveling in opposite directions at times, indicating that they can't all be right. From what I have observed I feel this is an explanation of earlier reported hunting swings across this Northwest interconnection that was observed to occur a few times a minute in a plain showing on the charts. But the case is different with modern precision governors, contrary to the commonly expressed fear of "governors fighting each other," for if all are very sensitive to start early in any speed change, and are stabilized to stop where needed through proper dashpot action insured by correct field adjustments, they don't do the wrong thing any more than does some other highly developed precision apparatus. Then with all working correctly in response to any change in speed, their benefits are cumulative in maintaining close speed.

To bear out these statements by referring to a situation of interconnection and power regulation that is a very close parallel to the problem under discussion, I want to say that during the past year I have been working on improvements on governors where a rough mining load at one end near a group of hydro plants is connected over the mountains with a larger system which has a regular lighting and commercial load but uses an automatic frequency controller. The situation was just the same as here, in that the tie-line loading must not be allowed to go high enough to cause difficulty. Hence in order to prevent the heavy mining load fluctuations from flowing through the interconnection, these changes must be absorbed largely on their own system, that is, by their own hydro units. Now this must be done in spite of the average frequency controller on the other system. This called for the highest order of sensitivity in these governors, also the fastest rate of operation practicable. By modernizing these governors, they were put into the class of good modern governors and by using the very smallest droop practicable, they were enabled to respond well to every quick change of speed to take most of the load changes on their own system. In order to help hold the steady-state loading desired in the tie line, a telemetering arrangement was put in to indicate

in the controlling station the power flow in the interconnection. This is valuable to the operator in avoiding slow drifts at any time including those during the beginning and end of working shifts at the mines.

In order to assist in this holding of the average loading in the tie line, it is the plan to go farther and make the whole thing automatic, by arranging to put this tie-line loading influence directly on the governors. This is being done, however, in a manner considerably different from the usual practice of using the synchronizing motor, by making the action direct on the governor controls. It is hoped that more operating results of this whole equipment may be reported later.

Sherwin H. Wright (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): In system planning and design it is usually transient stability, rather than steady-state stability that receives first consideration. This is logical, for steady-state stability limits are usually much higher and less important than the transient stability limits. Attention has therefore been focused for some time on methods of increasing transient stability limits, resulting in such developments as high-speed breakers and relays, quick-response excitation, and most recently, high-speed reclosing breakers.

During this development period system interconnections have become the rule rather than the exception and while transient stability of such interconnections is still lower than steady-state limits, yet the latter are for various reasons quite important, as in the case described in this paper by Pierce and Hamilton. The authors describe a case involving several large-size systems as evidenced by the capacities given in the article:

	Kilowatts
The Montana Power Company	250,000
The Washington Water Power Company	200,000
Puget Sound Power and Light Company	300,000
Pacific Power and Light Company and Northwestern Electric Company	120,000
Portland General Electric Company	175,000
Washington Gas and Electric Company	30,000

Thus it is seen that the total generating capacity involved is considerable, and it is quite probable that there are similar system groups in existence where phase-angle control apparatus can be and will be successfully applied.

It is pertinent to note that this phase-angle control equipment, since it controls the phase angle, is applicable in situations where phase-angle difference is a suitable and preferable control index. In the application described by the authors it was recognized (1) that the highest limit is the steady-state stability limit, (2) that the steady-state voltage limit is somewhat lower, and (3) that the control should be set for a value lower than (2) in order to allow margin for continual power swings between the systems.

As stated by the authors, the reason that kilowatt loading in itself is not a proper index is because along the interconnection there are loads which vary in both location and magnitude; such a situation gives phase-angle the preference over kilowatt loading as a control index. Under such conditions of variable location and magnitude of intermediate loads, phase-angle control may find successful application in not only cases where steady-state stability or steady-state voltage determines the practical operating limit, but also in cases where the practical limit is determined by transient stability for faults on the interconnection itself.

H. L. Melvin (Ebasco Services, Inc., New York, N. Y.): This discussion of the paper by Messrs. Pierce and Hamilton is presented for the purpose of amplifying somewhat the section dealing with operating experience. Because of the familiarity of the discusser with the interconnected operation of the Pacific Northwest systems during the past several years, the liberty is being taken of relating two or three items of interest which might more properly be presented by representatives of the several utility companies.

The paper gives a brief report of the high-speed chart-marking tests at interconnection points and controlling power stations. It was suspicioned that variations in governor sensitivity and dead time between the closing of governor-motor contacts and the kilowatt response of the generators were responsible to a large degree for the occasional large power swings and to some extent the amplitude of the regularly occurring swings. To check this suspicion, a photoelectric frequency recorder with an auxiliary mechanical pen was borrowed from the General Electric Company and preliminary tests were made to determine the characteristics of several governors on the interconnected systems. These tests demonstrated conclusively that unco-ordinated governor and automatic phase-angle control action could be accountable for the magnitude of at least a part of the power swings. The tests were not complete nor was the frequency recorder alone adequate for the purpose. Accordingly, the Washington Water Power Company purchased and has just received a General Electric, two-element, photoelectric recorder which will make a record of frequency and kilowatts; also, it has two auxiliary pens for mechanical attachment, all on one variable high-speed chart. It is planned to use this instrument for analyzing, adjusting, and co-ordinating the operation of governors, also automatic tie-line load-control equipment on the interconnected systems. The recording and analyzing of power flow at interconnection points with variations in system frequency also can be accomplished.

Since the paper was prepared, there has been placed in service an automatic tie-line load-control equipment of General Electric Company manufacture between the systems of the Puget Sound Power and Light and The Washington Water Power companies. Kilowatts interchange on the Chelan-Wenatchee interconnection is transmitted by carrier signals to the White River plant on the Puget Sound Company's system and the output of this plant is automatically controlled to hold the interchange at desired values. It, like the automatic phase-angle equipment between Washington and Montana, is working successfully.

Though all of the systems from Montana to the Pacific Coast are now operated successfully in parallel, it is expected that improvements will be realized through further application of automatic load-control equipment and better co-ordination of governor and automatic control action after completion of tests with the photoelectric frequency and kilowatt meter. Progress will be made only if this work is carried on in the splendid co-operative spirit which exists among the operating organizations; also between the electrical, hydraulic, and mechanical engineers involved.

It should be remembered that the capacities of the interconnections are rather limited and distances in the Northwest are relatively great. However, with maximum utilization of the interconnection facilities it is believed that present capacities will be adequate for some time. Economics and service are controlling considerations rather than the control of interchange to precise demand values, which in reality should have little if any place in interchange agreements.

R. E. Pierce and B. W. Hamilton: The authors are gratified at the interest shown in the new method of control described. We concur in the view of the several discussers, and would like to emphasize some of these points.

Mr. Geyer brought out very well that the apparent lack of co-ordination between the various governors and with the automatic control equipment would perhaps not exist were the governors of modern and sensitive design and properly adjusted. We also anticipate that somewhat improved co-ordination and over-all system performance can be obtained, even with the present installed governors, following completion of the further studies mentioned and following whatever maintenance and adjustments that may be indicated as necessary. This will probably include making certain governors less sensitive for small speed variations (and considerable more thought being given to speed-droop setting). Mr. Geyer also describes a somewhat parallel case, where it is planned that automatic control of an interconnection will result in practically all of the load swings on one system being absorbed on that system. The results secured will be of interest, and we hope will be reported.

As Mr. Marquis points out, some form of automatic control is usually necessary to maintain scheduled power flows between systems, but that in the situation described, we were attempting to do somewhat more than maintain a scheduled flow. Inasmuch as any predetermined scheduling of power flow at some arbitrarily selected interconnection point (usually wherever ownership of facilities changes) does not always result in maximum utilization of the transmission facilities, it is pertinent, as Mr. Melvin has done, to raise the question as to whether definite scheduling of interchange flows to precise demand values is always the best over-all practice. In our opinion, there are probably many interconnections where the full capabilities of

Static Power Limits of Synchronous Machines

By CHARLES F. DALZIEL
ASSOCIATE AIEE

THIS paper presents an analysis of the determination of static power limits of power systems and offers an accurate method considering resistance, shunt loads, saliency, and saturation. The conventional methods of determining the static power limits of systems composed of synchronous machines and shunt loads based on unsaturated cylindrical-rotor theory give only approximate results. It is fortunate that the actual maximum power transfer is generally larger than the calculated value obtained from the customary analysis. Machine saturation and saliency increase the power limit, the difference decreasing with increased system impedance. The validity of the method is shown by the check between experimental values obtained from three small machines and theoretical curves. It was found that errors due to neglecting saturation are more significant than those due to neglecting saliency.

Static power limits are important because they may be exceeded under emergency conditions, even though the system is designed to operate well below these limits normally. Although transient stability will probably continue to be regarded the most important factor limiting the power transfer through most practical systems, recent accomplishments which increase the transient limit reduce the difference between the transient and static power limits, and an accurate analysis of static power limits is of increasing importance. It is possible that studies made on operating systems might indicate minor or preferred changes in load dispatching which would result in higher power limits and greater margins of stability, ultimately reflecting increased reliability of system operation.

Much data included in this paper were obtained by graduate and senior students under the writer's supervision. No serious experimental difficulties were encountered, and a number of the runs were repeated and rechecked at various times during the past three years.

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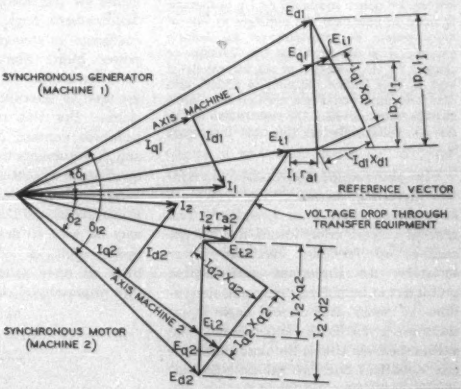
1. For all numbered references, see list at end of paper.

It has been shown that inertia effects may cause a difference between the maximum power output and the static stability limit.[1] In the experimental work reported here, the difference between the maximum power and static stability limits was negligible for synchronous generator-motor systems. Systems involving two generators and shunt loads were much more stable, and it was possible to operate the machines with displacement angles up to 91 electrical degrees. However, when the displacement angles exceeded that corresponding to maximum power output, the machines were in unstable equilibrium and required very careful supervision, any slight misadjustments causing immediate loss of synchronism. It was concluded that for practical purposes static stability may be regarded as a problem of stable equilibrium in which all transient phenomena and inertia effects are neglected.[2] This is in agreement with the recent report of the AIEE committee on the subject.[2]

Figure 1. Vector diagram — synchronous generator-motor system



The stability limit is determined by the first synchronous machine to reach its maximum power output. A system is considered stable if all the machines are operating in stable equilibrium. It will be unstable if any machine is unstable.[2] A machine operates in stable equilibrium if each additional increment of load is accompanied with a corresponding increasing increment of displacement angle. For each machine a critical load will finally be reached which is the maximum load the machine can carry and operate in stable equilibrium with respect to the other machines. If further attempt be made to load the facilities should be utilized, and efforts made to equitably share the burdens and benefits between the interconnecting parties, rather than to make extraordinary efforts to control the operation to maintain arbitrarily predetermined interchange values.

We agree with the opinion expressed by Mr. Wright that phase-angle control may find application where the practical limit is determined by transient stability, as well as in cases, such as the one described by the authors, where it was desired to operate beyond the transient stability limit and as close as practicable to the steady-state limit. In either case, the phase-angle difference between systems is the basic determining factor between stable and unstable conditions.

machine, it will be found that increasing increments of displacement angle are accompanied by decreasing increments of load, and the machine will be unstable equilibrium.

Static stability refers to the normal power transfer through a system, and should not be confused with transient stability in which the effects of disturbances are considered. Two static power limits are distinguished:

I. The steady-state power limit is defined as the maximum power that may be transferred through a network without loss of synchronism when the machine excitations are maintained constant at the values necessary to produce the terminal voltages required for the initial system loading. It is assumed that the disturbance caused by the addition of each increment of load has ceased before the next increment is applied.[4]

II. The dynamic power limit is defined as the maximum power that may be transferred through a network without loss of synchronism when the machine excitations are varied either manually or by automatic devices to maintain the voltages at one or more points at constant, or at definite values. It is assumed that the disturbance caused by the addition of an increment of load is over before the next is added, and that the increments are applied at a slow enough rate to permit the restoration of the system voltages before the next increment is added.

The power-angle equations for a system involving n salient-pole machines have been taken from Longley.[5] The general case is complicated due to the number of variables involved. Fortunately, the important two-machine problem can be solved easily and derivations of power and current-angle equations are given in the appendices. The author believes this is the first time concise equations for two salient-pole machines have been published.[6]

Determination of the Steady-State Power Limit

The machine internal voltages are determined from the known or assumed load and substituted in equations 11 and 12 (see figure 1). The displacement angle (δ) is arbitrarily increased and the first machine to reach its maximum power output determines the power limit of the system. The steady-state limit is of minor interest in power systems, but it is important in determining the pull-out torque in synchronous machines using fixed excitation or manual control.

Determination of the Dynamic Power Limit

The dynamic power-angle curve intersects each of a family of steady-state power-angle curves at points of known voltage and current. The limit of stable equilibrium of a synchronous machine occurs when the dynamic curve intersects the first steady-state curve at its maximum point. This point may be determined by plotting stability coefficients for increasing values of power or displacement angle. The first stability coefficient to change sign determines the power limit. Since the voltages and currents are known, equations 13 and 14 are used to determine the stability coefficients. For this case the system impedances contain X_q of the machines, and E_d represents the voltage behind the quadrature synchronous reactance.

Although not stated in the paper by Edith Clarke and Lorraine,[2] their analysis may be used to determine the dynamic power limit of systems composed of three or more salient-pole machines if their equations 1 to 8 contain the X_q of the machines and the corresponding voltages behind X_q.

For cases in which the system voltages are maintained constant, all shunt loads including synchronous condensers and induction motors may be represented approximately by simple shunt impedances. This treatment assumes that the induction motor portion of the system load remains stable. Since the maximum power transfer is ordinarily limited by the synchronous machines on the system, this assumption should not introduce significant errors in the result. See references 2 and 7 for accurate treatment.

Consideration of Saturation

Saturation in the synchronous machines was neglected in the preceding discussion. The power or current equations give accurate results if saturated values of the machine X_q corresponding to the machine air gap voltages are used.[6,8] Determination of the steady-state power limit is complicated by variations of X_q and the correction for saturation with current. Fortunately, the dynamic limit, which is the most important from a practical standpoint, may be determined easily, since the voltages are known and the current or power is the independent variable. The saturated X_q corresponding to the air-gap voltage is obtained and E_q determined. These values are then used to determine the stability coefficients using equations

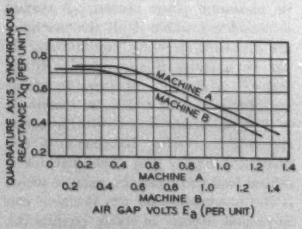


Figure 2. Variation of quadrature-axis synchronous reactance with air-gap voltage

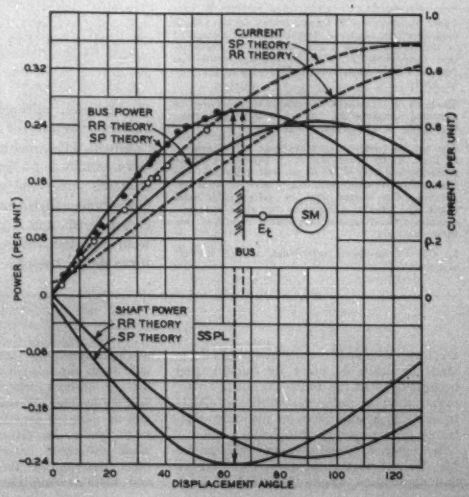


Figure 3. Unsaturated synchronous motor operating from an infinite bus

SP—Salient pole

RR—Round rotor

SM—Synchronous motor

SSPL—Steady-state power limit

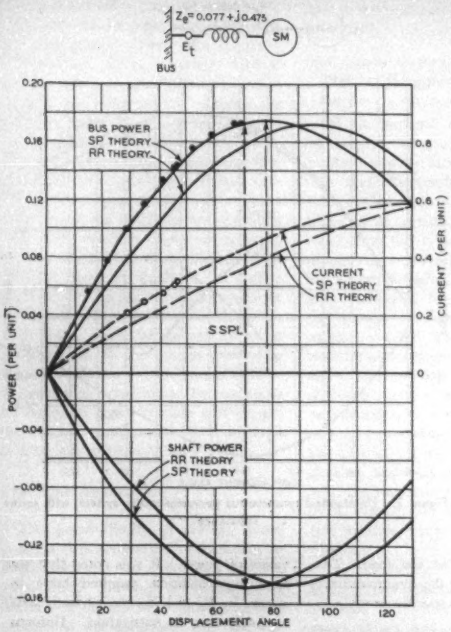


Figure 4. Unsaturated synchronous motor operating from an infinite bus, with series impedance

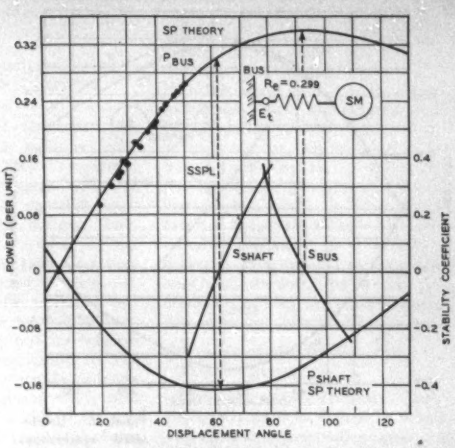


Figure 5. Unsaturated synchronous motor operating from an infinite bus, with series resistance

13 and 14. In this case the system impedances, Z_{11}, Z_{22}, and Z_{12} contain the machine X_{ed}, and the E_{ds} are the corresponding voltages behind the X_{ed}.

It is believed that the dynamic power limit may be approached in large power systems, since variations in load generally occur at a slow enough rate to permit modern voltage regulators and governors to maintain the system voltage and frequency. The method permits an accurate determination including resistance, saliency, and saturation. It should be of particular value in determining the maximum power transfer over single-circuit tie lines, as well as the emergency power limits of transmission systems in general.

Experimental Results

The laboratory work centered about two similar synchronous machines rated: 15 kva, 220 volts, 39.4 amperes, 1,200 rpm, 60 cycle, 3 phase. The quadrature axis synchronous reactances versus air-gap voltage are given in figure 2.*

* Per unit quantities are used throughout this discussion. 1.00 per unit power equals 15 kw.

The unsaturated machine constants are:

Machine A. $R_a = 0.044$, $X_l = 0.072$, $X_d = 1.15$, $X_q = 0.742$.

Machine B. $R_a = 0.045$, $X_l = 0.071$, $X_d = 1.10$, $X_q = 0.722$.

Steady-State Power and Current Characteristics, Unsaturated Synchronous Motor

Figures 3, 4, and 5 show calculated and test results of machine A, energized from an infinite bus at half voltage. With the excitation held constant, values of power and current were obtained for various loads up to pull-out. Theoretical power and current-angle curves using both round-rotor and salient-pole analyses were plotted to compare results. Although the round-rotor theory yields poor results with respect to displacement angle, the differences at pull-out were small, and the errors decreased with increased system impedance. The difference between the shaft and bus power was due to the I^2R loss in the machine and series impedance. Motor power was plotted negative to avoid confusion.

It was concluded that the common method of determining the *unsaturated* power limits should give results of sufficient accuracy for most engineering purposes. It will be shown that the effects of saturation are likely to cause much greater errors than those caused by neglecting saliency.

Steady-State Power Angle Curves, Synchronous Generator-Motor System

Figures 6 and 7 show calculated and test results with machine B driving machine A. With the excitations held constant, corresponding to approximately half voltage at no load, values of power were obtained for various loads up to pull-out. Again the agreement between test and calculated results substantiates the analysis and should lead to a better understanding of the unsaturated synchronous machine.

Figure 8 shows similar results under saturated conditions. For the steady-state test, the machine excitations were held constant corresponding to rated voltage at no load. The power-angle curve was obtained as before. Calculated power-angle curves using unsaturated machine constants are included for comparison and indicate the necessity for considering saliency and saturation if accurate results are required. It is obvious that this statement applies to both steady-state and dynamic power limits. It was concluded that errors due to neglecting saturation are more

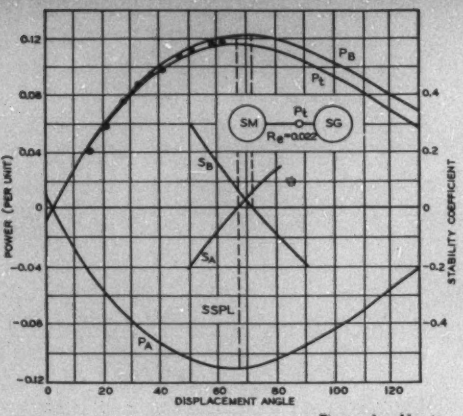


Figure 6. Unsaturated synchronous generator-motor system

SG — Synchronous generator

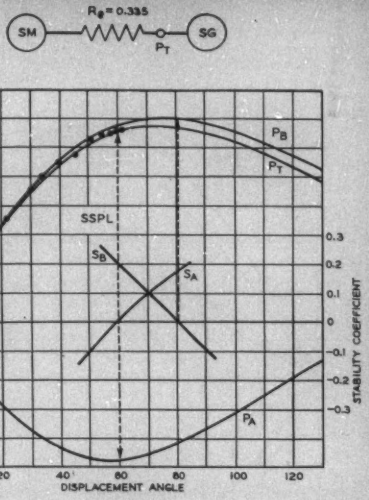


Figure 7. Unsaturated synchronous generator-motor system, with series resistance

significant than those due to neglecting saliency.

For the dynamic stability test, the machine excitations were varied to hold the motor terminal voltage and power factor constant at unity. The dynamic limit of the system was not reached due to limitations of equipment. The correlation between observed and calculated values for this highly saturated case is an indication of how accurately saturation may be included, since E_2 was held constant at rated value and E_1 varied from 1.00 to about 1.25.

Two Synchronous Generators, Variable Shunt Load, and Series Impedance

In this test an attempt was made to duplicate the general two-machine problem. A variable three-phase balanced resistance load connected to the terminals of generator *A* was energized from both generators. The power supplied at the load was held in the ratio $P_1/P_2 = 2/1$, and the frequency was held at 60 cycles. Starting at no load, the delivered power-angle curves were obtained by gradually increasing the shunt load.

For the steady-state test the machine excitations were held constant corresponding to a no-load voltage, $E_2 = 0.4515$. The load was applied and the power-angle curve obtained. It is interesting to note that the two generators were inherently more stable than during the generator-motor tests and several points were obtained in the region of unstable equilibrium (see figure 9).

For the dynamic test, the machine excitations were varied to hold the load voltage constant ($E_2 = 0.4515$), and the power factors unity at the load. The method of calculating the dynamic curve will be illustrated by a specific example.

Let $P = 0.50$, $P_1 = 0.333$, and $P_2 = 0.167$

$I = P/E = 1.108/\underline{0}$.

$I_1 = 0.738/\underline{0}$ and $I_2 = 0.370/\underline{0}$

The series impedance, $Z_e = 0.123 + j0.692 = 0.702/\underline{79.9}$

$$E_1 = E_2 + I_1 Z_e = 0.4515/\underline{0} + 0.738/\underline{0} \times 0.702/\underline{79.9} = 0.744/\underline{43.2}$$

$$E_{g1} = E_1 + I_1 Z_h = 0.744/\underline{43.2} + 0.738/\underline{0}(0.045 + j0.071) = 0.804$$

$X_{g1} = j0.571$ from figure 2

$$E_{g1} = E_1 + I_1 Z_{g1} = 0.744/\underline{43.2} + 0.738/\underline{0}\,(0.045 + j0.571) = 1.096/\underline{58.2}$$

By a similar process, $X_{g2} = j0.723$ and $E_{g2} = 0.538/\underline{29.7}$

$\delta_{12} = 58.2 - 29.7 = 28.5$

$z_1 = (0.045 + 0.123) + j(0.571 + 0.692) = 1.272/\underline{82.4}$

$z_2 = (0.044 + j0.723) = 0.724/\underline{86.5}$

$z_3 = E_3/I = \dfrac{0.4515/\underline{0}}{1.108/\underline{0}} = 0.407/\underline{0}$

$z_{12} = z_1 + z_2 + z_1 z_2/z_3 = 3.14/\underline{129.6}$

$\alpha_{12} = -39.6$

$S_1 = \cos(28.5 + 39.6) = 0.373$ from equation 13

$S_2 = \cos(28.5 - 39.6) = 0.981$ from equation 14

The complete curve was obtained by repeating the process using increasing values of power. It was noted that this operating condition required large increases in E_1, and X_{g1} varied from 0.700 to 0.468 due to saturation. Unfortunately the dynamic stability limit was not reached due to limitations of the equipment.

The dash-line curves of figure 10 illustrate the determination of the dynamic limit when the machine excitations were varied to hold both generator terminal voltages equal at 0.4515. The stability coefficient S_{1a} indicates a theoretical maximum delivered load of 0.280 per unit. Although it was possible to supply a slightly greater load, the system became very unstable and soon lost synchronism.

The solid-line curves of figure 10 illustrate the determination of the dynamic limit when a 7.5-kva 220-volt 19.7-ampere cylindrical-rotor machine used as a synchronous condenser was connected at the load to maintain voltages. During this test the power supplied to the load was held in the ratio $P_1/P_2 = 2/1$, and machine *A* was held at unity power factor. The losses of the condenser were considered as part of the load. Stability coefficient S_{1b} determines the stability limit of the system with a delivered power equal to 0.270 per unit.

The assumption that a synchronous condenser can be replaced with a static condenser for dynamic analysis is verified from inspection of the curve. Experi-

mental points using three different static condensers are in good agreement with the other results.

Calculated curves showing various factors which may limit the power transfer for this typical system are given in figure 11, in which the ratio P_1/P_3 has been varied over a wide range. The assumed operating conditions were the same as those of the preceding test. The rapid increase in dynamic stability occurs when the machines are operating with nearly constant displacement angles between them, a condition similar to the dynamic curve of figure 9. A similar study applied to practical systems might indicate that large increases in the maximum power would be realized by minor redistribution of the system generating capacity. Curves of this type should be of interest in determining the conditions for optimum power transfer and suggest the extreme conditions to be considered in transient stability studies.

Practical Application

The power limits of several actual systems were determined to illustrate the possibilities in the way of practical application. Although the actual power limits were unknown, available operating experience was consistent with the conclusions reached. The reactances of most of the machines were not available and typical unsaturated values were used.[3,9,10] These were multiplied by 0.90 to give a conservative correction for saturation.[11]

San Diego Consolidated Gas and Electric-Southern California Edison Interconnection

In the summer of 1932, the small 50/60-cycle frequency converter interconnection of the San Diego Consolidated Gas and Electric-Southern California Edison Company was operated for a considerable period in utilizing "spillway" from the Edison system. During certain times of the day when the system loads were changing most, it was a common experience for the converter load to increase to some value slightly in excess of 7,500 kw, and its breakers would trip on out-of-step operation. The converter excitation system included one automatic voltage regulator which could be connected to either side of the machine. It was found possible to choose the system on which instability would develop, and best results were obtained with the regulator connected on the 60-cycle system. It was desired to hold the average converter load at about 5,000 kw.

In calculating the dynamic power limit it was assumed that all terminal voltages were maintained constant at rated values and that the San Diego system loads remained constant at the average values given in figure 12. It was concluded that the 60-cycle side of the converter should control the dynamic stability of the system and permit a maximum load transfer of approximately 16,400 kw (see figure 13). The steady-state power limit of the 50-cycle system was determined at approximately 8,000 kw assuming constant converter excitation corresponding to an initial load transfer of 5,000 kw. The result compares favorably with operating experience and stresses the value of automatic excitation equipment. It is the writer's opinion that the higher power limit could have been approached and the operating difficulties reduced had modern excitation equipment been provided.

Hetch Hetchy-Pacific Gas and Electric System

The City of San Francisco's Hetch Hetchy system is an example of a large hydroelectric project feeding power over a long transmission line into an infinite bus (see figure 14). Since the lines were originally designed for 154 kv, but were insulated and operate at approximately 110 kv, and the operating orders limit the power transmitted over one line to 40,000 kw, it was thought that a study of the maximum or emergency power limits might be valuable as well as instructive. The dynamic power limit was determined at approximately 92,500 kw for normal operating voltages and

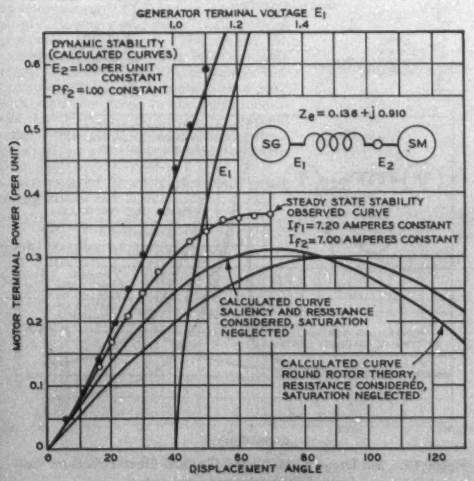


Figure 8. Saturated synchronous generator-motor system with series impedance

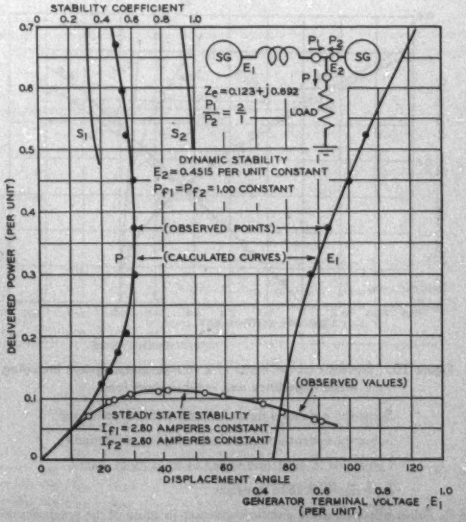


Figure 9. Steady-state and dynamic power limits of a two-generator system including series impedance and variable shunt load

one line in service. With the exception of the generator quadrature reactances, actual system constants were used.[12]

Several times during emergency switching and trip-outs, full load (approximately 77,000 kw) was dumped on the remaining line for a few minutes until the station operators had time to readjust the governors. It was reported that although there was naturally quite a disturbance when one line went out, (depending upon the severity and location of the trouble) in no case was there any indication of instability when one line was carrying the load. This is consistent with the calculated value and should increase confidence in the proposed analysis.

Boulder Dam System

The dynamic power limit of the Boulder Dam-City of Los Angeles system should be of considerable importance, since the system originally designed for a transient stability limit of 235,000 kw has already carried peak loads of approximately 281,000 kw. System data were taken from Scattergood's paper,[13] and supplemented with the actual quadrature reactances of the Boulder Dam generators. The equivalent steam-plant impedances were assumed by the writer. The Los Angeles load was assumed at 0.80 power factor lagging and the theoretical synchronous condenser kva required to maintain the system voltages was computed. Using a factor of 0.80 to allow for imperfections in assumptions, system hunting, etc., the dynamic delivered power limit of the 275-kv transmission system was approximately 294,000 kw with the steam plant floating. The power limit increased materially as the steam plant was given load. It may be interesting to mention that similar studies using round-rotor theory and neglecting saturation lowered the theoretical dynamic power limit 43,000 kw. Perhaps a more important problem involves the dynamic power limit with one line section out of service; however, lack of time prevented extended investigation.

The above examples and practical problems should be sufficient to illustrate the application of the static stability limits of power systems. It is believed that the effects of saliency and saturation are of sufficient importance to warrant consideration, especially for practical cases where an accurate determination of the maximum power limits are under question.

Appendix I

Derivation of Power-Angle Equations

The following is an extension of the familiar power-angle equations. Lowercase bold-face letters are used to denote

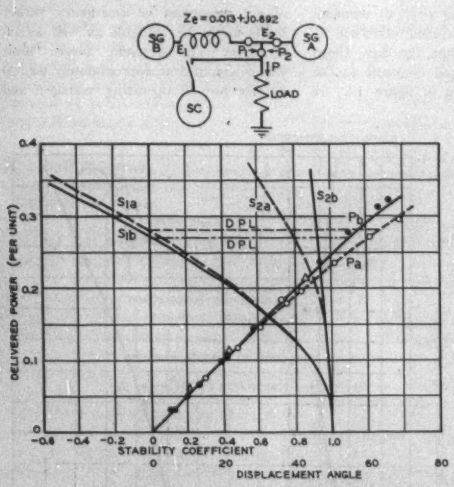


Figure 10. Dynamic power limits of a two-generator system including series impedance and variable shunt load

Subscript *a* denotes data obtained with no condenser

Subscript *b* denotes data obtained using condensers

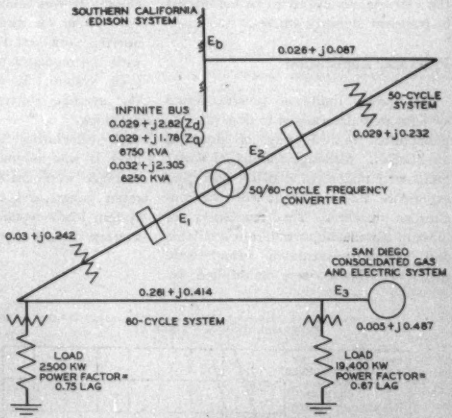
Generator *A* excitation varied to hold P_b at unity

$E_1 = E_2 = 0.4515$ constant

△ Points obtained using a static condenser in place of the synchronous condenser

DPL—Dynamic power limit *SC*—Synchronous condenser

Figure 11. Factors controlling power limit of system



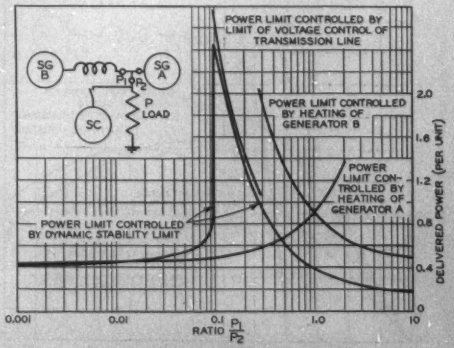


Figure 12. San Diego Consolidated Gas and Electric-Southern California Edison Interconnected system

System impedances on 20,000-kva base

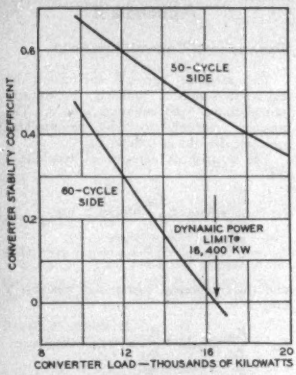


Figure 13. Dynamic power limits of 50/60-cycle converter

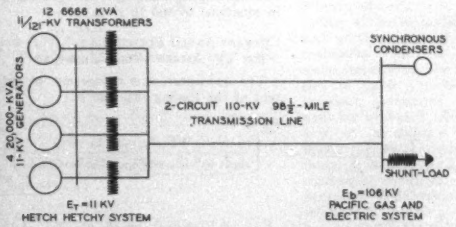


Figure 14. Hetch Hetchy-Pacific Gas and Electric interconnected system

vectors, and capitals represent scalars. Subscript q used with current or voltages represents the quadrature-axis component; similarly, subscript d denotes the direct-axis component. The first numerical subscript following q or d refers to the voltage producing that current. The second numerical subscript, or when only one subscript is used, denotes the branch or machine considered. Subscripts q or d used with reactance refer to the synchronous-machine constants according to present usage. The system impedances are denoted by a double subscript notation consistent with the above.[2,5,6,10,14]

Referring to figure 1, the shaft power output of machine 1 is:

$$P_1 = E_{q1} I_{q1} \tag{1}$$

By the principle of superposition

$$I_{q1} = I_{q11} - I_{q21} \ldots - I_{qn1} \tag{2}$$

$$I_{d1} = I_{d11} - I_{d21} \ldots - I_{dn1} \tag{3}$$

also

$$i_{11} = \frac{e_{q1}}{z_{11}}, \; i_{21} = \frac{e_{q2}}{z_{21}}, \; \ldots \; i_{n1} = \frac{e_n}{z_{n1}}$$

The impedances contain the system parameters, machine resistance, and the quadrature-axis synchronous reactance. Obviously the scalar value of $Z_{1n} = Z_{n1}$, and $\phi_{1n} = \phi_{n1}$. Let δ_n be the angle of e_{qn} from a reference.

$$\delta_{1n} = \delta_1 - \delta_n$$

Introducing scalars:

$$I_{q11} = \frac{E_{q1}}{Z_{11}} \cos \phi_{11}, I_{q21} = \frac{E_{q2}}{Z_{12}} \cos (\delta_{12} + \phi_{12}), \ldots$$

$$\ldots I_{qn1} = \frac{E_{qn}}{Z_{1n}} \cos (\delta_{1n} + \phi_{1n})$$

and

$$I_{d11} = \frac{E_{q1}}{Z_{11}} \sin \phi_{11}, I_{d21} = \frac{E_{q2}}{Z_{12}} \sin (\delta_{12} + \phi_{12}), \ldots$$

$$\ldots I_{dn1} = \frac{E_{qn}}{Z_{1n}} \sin (\delta_{1n} + \phi_{1n})$$

Substituting $\alpha_{1n} = 90 - \phi_{1n}$ in the foregoing:

$$I_{q1} = \frac{E_{q1}}{Z_{11}} \sin \alpha_{11} + \frac{E_{q2}}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) \ldots . + \frac{E_{qn}}{Z_{1n}} \sin (\delta_{1n} - \alpha_{1n}) \tag{4}$$

and

$$I_{d1} = \frac{E_{q1}}{Z_{11}} \cos \alpha_{11} - \frac{E_{q2}}{Z_{12}} \cos (\delta_{12} - \alpha_{12}) \ldots . - \frac{E_{qn}}{Z_{1n}} \cos (\delta_{1n} - \alpha_{1n}) \tag{5}$$

Substituting (4) in (1):

$$P_1 = \frac{E_{q1}^2}{Z_{11}} \sin \alpha_{11} + \frac{E_{q1} E_{q2}}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) + \frac{E_{q1} E_{q2}}{Z_{13}} \sin (\delta_{13} - \alpha_{13}) \ldots + \frac{E_{q1} E_{qn}}{Z_{1n}} \sin (\delta_{1n} - \alpha_{1n})$$

Similarly,

$$P_k = \frac{E_{qk}^2}{Z_{kk}} \sin \alpha_{kk} + \frac{E_{qk} E_{q1}}{Z_{k1}} \sin (\delta_{k1} - \alpha_{k1}) + \frac{E_{qk} E_{q2}}{Z_{k2}} \sin (\delta_{k2} - \alpha_{k2}) \ldots + \frac{E_{qk} E_{qn}}{Z_{kn}} \sin (\delta_{kn} - \alpha_{kn}) \tag{6}$$

The relation between E_1 and E_q is apparent from figure 1:

$$E_{q1} = E_{q1} + I_{d1}(X_{d1} - X_{q1})$$

Substituting equation 5:

$$E_{q1} = E_{q1} \left(1 + \frac{(X_{d1} - X_{q1})}{Z_{11}} \cos \alpha_{11} \right) - E_{q2} \frac{(X_{d1} - X_{q1})}{Z_{12}} \cos (\delta_{12} - \alpha_{12}) \ldots - E_{qn} \frac{(X_{d1} - X_{q1})}{Z_{1n}} \cos (\delta_{1n} - \alpha_{1n})$$

Let

$$A_1 = 1 + \frac{(X_{d1} - X_{q1})}{Z_{11}} \cos \alpha_{11}$$

$$A_n = 1 + \frac{(X_{dn} - X_{qn})}{Z_{nn}} \cos \alpha_{nn}$$

$$B_{12} = \frac{(X_{d1} - X_{q1})}{Z_{12}}$$

$$B_{kn} = \frac{(X_{dk} - X_{qk})}{Z_{kn}}$$

Then

$$E_{q1} = A_1 E_{q1} - E_{q2} B_{12} \cos (\delta_{12} - \alpha_{12}) - E_{q3} B_{13} \cos (\delta_{13} - \alpha_{13}) \ldots - E_{qn} B_{1n} \cos (\delta_{1n} - \alpha_{1n})$$

Similarly

$$E_{1k} = -E_{q1} B_{k1} \cos (\delta_{k1} - \alpha_{k1}) \ldots + A_k E_{qk} \ldots - E_{qn} B_{kn} \cos (\delta_{kn} - \alpha_{kn}) \tag{7}$$

Values of $E_{q1}, E_{q1}, E_{qk} \ldots E_{qn}$, are obtained from simultaneous solution of these equations, for example, see equation 8.

$$E_{qk} = \frac{\begin{vmatrix} A_1 & -B_{12}\cos(\delta_{12}-\alpha_{12}) & \ldots & E_{q1} & \ldots & -B_{1n}\cos(\delta_{1n}-\alpha_{1n}) \\ -B_{21}\cos(\delta_{21}-\alpha_{21}) & A_2 & \ldots & E_{q2} & \ldots & -B_{2n}\cos(\delta_{2n}-\alpha_{2n}) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -B_{k1}\cos(\delta_{k1}-\alpha_{k1}) & -B_{k2}\cos(\delta_{k2}-\alpha_{k2}) & \ldots & E_{1k} & \ldots & -B_{kn}\cos(\delta_{kn}-\alpha_{kn}) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -B_{n1}\cos(\delta_{n1}-\alpha_{n1}) & -B_{n2}\cos(\delta_{n2}-\alpha_{n2}) & \ldots & E_{qn} & \ldots & A_n \end{vmatrix}}{\begin{vmatrix} A_1 & -B_{12}\cos(\delta_{12}-\alpha_{12}) & \ldots & -B_{1k}\cos(\delta_{1k}-\alpha_{1k}) & \ldots & -B_{1n}\cos(\delta_{1n}-\alpha_{1n}) \\ -B_{21}\cos(\delta_{21}-\alpha_{21}) & A_2 & \ldots & -B_{2k}\cos(\delta_{2k}-\alpha_{2k}) & \ldots & -B_{2n}\cos(\delta_{2n}-\alpha_{2n}) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -B_{k1}\cos(\delta_{k1}-\alpha_{k1}) & -B_{k2}\cos(\delta_{k2}-\alpha_{k2}) & \ldots & A_k & \ldots & -B_{kn}\cos(\delta_{kn}-\alpha_{kn}) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -B_{n1}\cos(\delta_{n1}-\alpha_{n1}) & -B_{n2}\cos(\delta_{n2}-\alpha_{n2}) & \ldots & -B_{nk}\cos(\delta_{nk}-\alpha_{nk}) & \ldots & A_n \end{vmatrix}} \tag{8}$$

The power equations for the two machines are obtained from equation 6. Substituting $\delta_{21} = -\delta_{12}$ and rearranging:

$$\left.\begin{aligned} P_1 &= \frac{E_{q1}^2}{Z_{11}} \sin \alpha_{11} + \frac{E_{q1}E_{q2}}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) \\ P_2 &= \frac{E_{q2}^2}{Z_{22}} \sin \alpha_{22} - \frac{E_{q1}E_{q2}}{Z_{12}} \sin (\delta_{12} + \alpha_{12}) \end{aligned}\right\} \quad (9)$$

From equation 7:

$$E_{d1} = A_1 E_{q1} - E_{q2} B_{12} \cos (\delta_{12} - \alpha_{12})$$
$$E_{d2} = -E_{q1} B_{21} \cos (\delta_{12} + \alpha_{12}) + A_2 E_{q2}$$

Solving for E_{q1} and E_{q2} and simplifying:

$$\left.\begin{aligned} E_{q1} &= \frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}} \\ E_{q2} &= \frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}} \end{aligned}\right\} \quad (10)$$

Substituting equation 10 in equation 9 gives the power-angle equations for two salient-pole machines. The stability coefficients are determined by differentiation. Only significant terms are included. Common multiplying factors and terms becoming negligible at the maximum power output have been omitted.

Power-Angle Equations for Two Salient-Pole Machines

The shaft power output of the leading machine is:

$$P_1 = \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right]^2 \frac{\sin \alpha_{11}}{Z_{11}} + \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \frac{\sin (\delta_{12} - \alpha_{12})}{Z_{12}}$$

The stability coefficient of the leading machine is:

$$S_1 = A_1 A_2 E_{d1} E_{d2} \cos (\delta_{12} - \alpha_{12}) + A_1 E_{d2}^2 B_{12} \cos 2(\delta_{12} - \alpha_{12}) + A_2 E_{d1}^2 B_{21} \cos 2\delta_{12} - 2A_2 E_{d1} E_{d2} B_{12} \frac{Z_{12}}{Z_{11}} \sin \alpha_{11} \sin (\delta_{12} - \alpha_{12}) \quad (11)$$

The shaft power output of the lagging machine is:

$$P_2 = \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right]^2 \frac{\sin \alpha_{22}}{Z_{22}} - \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \frac{\sin (\delta_{12} + \alpha_{12})}{Z_{12}}$$

The stability coefficient of the lagging machine is:

$$S_2 = A_1 A_2 E_{d1} E_{d2} \cos (\delta_{12} + \alpha_{12}) + A_2 E_{d1}^2 B_{21} \cos 2(\delta_{12} + \alpha_{12}) + A_1 E_{d2}^2 B_{12} \cos 2\delta_{12} + 2A_1 E_{d1} E_{d2} B_{21} \frac{Z_{12}}{Z_{22}} \sin \alpha_{22} \sin (\delta_{12} + \alpha_{12}) \quad (12)$$

Where: δ_{12} is the displacement angle between the axes of machines 1 and 2 in electrical degrees. Z_{11}, Z_{22}, and Z_{12} are the driving point, receiving point, and transfer impedances, respectively, and contain X_q of the machines. α_{11}, α_{22}, and α_{12} are their associated angles ($\alpha = 90 - \phi_z$). In most cases the α angles are small, and the output of a generator is positive; similarly, the output of a motor is negative.

When the machines have round rotors the A constants become unity, the B terms zero, and the machine $X_q = X_d$, $E_1 = E_d$.

Power-Angle Equations for Two Round-Rotor Machines

$$P_1 = E_{d1}^2 \frac{\sin \alpha_{11}}{Z_{11}} + \frac{E_{d1}E_{d2}}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) \qquad S_1 = \cos (\delta_{12} - \alpha_{12}) \quad (13)$$

$$P_2 = E_{d2}^2 \frac{\sin \alpha_{22}}{Z_{22}} - \frac{E_{d1}E_{d2}}{Z_{12}} \sin (\delta_{12} + \alpha_{12}) \qquad S_2 = \cos (\delta_{12} + \alpha_{12}) \quad (14)$$

These equations are recognized as the familiar round-rotor power equations. They may be used to determine the power transfer between two round-rotor machines, or any two points of known voltage, E_{d1} and E_{d2}.

Appendix II

Derivation of Current Equations

The machine currents are given by equations 4 and 5. Similarly, the voltages are obtained from equation 7 or 8. The machine currents for the two-machine case are derived as follows:

The component currents of machine 1 are:

$$I_{q1} = \frac{E_{q1}}{Z_{11}} \sin \alpha_{11} + \frac{E_{q2}}{Z_{12}} \sin (\delta_{12} - \alpha_{12})$$

$$I_{d1} = \frac{E_{q1}}{Z_{11}} \cos \alpha_{11} - \frac{E_{q2}}{Z_{12}} \cos (\delta_{12} - \alpha_{12}) \quad (15)$$

and the component currents of machine 2 are:

$$I_{q2} = \frac{E_{q2}}{Z_{22}} \sin \alpha_{22} - \frac{E_{q1}}{Z_{12}} \sin (\delta_{12} + \alpha_{12})$$

$$I_{d2} = \frac{E_{q2}}{Z_{22}} \cos \alpha_{22} - \frac{E_{q1}}{Z_{12}} \cos (\delta_{12} + \alpha_{12}) \quad (16)$$

Substituting E_{q1} and E_{q2} from equation 10 in equations 15 and 16 gives the—

Current-Angle Equations for Two Salient-Pole Machines

The quadrature-axis component of current of the leading machine is:

$$I_{q1} = \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\sin \alpha_{11}}{Z_{11}} + \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\sin (\delta_{12} - \alpha_{12})}{Z_{12}}$$

The direct axis component of current of the leading machine is:

$$I_{d1} = \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\cos \alpha_{11}}{Z_{11}} - \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\cos (\delta_{12} - \alpha_{12})}{Z_{12}}$$

The total current is:

$$I_1 = \sqrt{I_{q1}^2 + I_{d1}^2} \quad (17)$$

at an angle $= \tan^{-1} I_{d1}/I_{q1}$ from the axis of machine 1.

The quadrature-axis component of current of the lagging machine is:

$$I_{q2} = \left[\frac{A_1 E_{d2} + E_{d1} B_{21} \cos (\delta_{12} + \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\sin \alpha_{22}}{Z_{22}} - \left[\frac{A_2 E_{d1} + E_{d2} B_{12} \cos (\delta_{12} - \alpha_{12})}{A_1 A_2 + B_{12} B_{21} \sin^2 \alpha_{12} - B_{12} B_{21} \cos^2 \delta_{12}}\right] \times \frac{\sin (\delta_{12} + \alpha_{12})}{Z_{12}}$$

and

$$I_{d2} = \left[\frac{A_1E_{t2}+E_{t1}B_{12}\cos(\delta_{12}+\alpha_{12})}{A_1A_2+B_{12}B_{21}\sin^2\alpha_{12}-B_{12}B_{21}\cos^2\delta_{12}}\right]\times\frac{\cos\alpha_{22}}{Z_{22}} - \left[\frac{A_2E_{t1}+E_{t2}B_{21}\cos(\delta_{12}-\alpha_{12})}{A_1A_2+B_{12}B_{21}\sin^2\alpha_{12}-B_{12}B_{21}\cos^2\delta_{12}}\right]\times\frac{\cos(\delta_{12}+\alpha_{12})}{Z_{12}}$$

$$I_2 = \sqrt{I_{q2}^2 + I_{d2}^2}$$
at an angle = $\tan^{-1} I_{d2}/I_{q2}$ (18)

When the machines have round rotors the A constants = 1, the B constants = 0, the machine $X_q = X_d$, and $E_t = E_d$.

CURRENT-ANGLE EQUATIONS FOR TWO ROUND-ROTOR MACHINES

$$I_{q1} = \frac{E_{d1}\sin\alpha_{11}}{Z_{11}} + \frac{E_{d2}\sin(\delta_{12}-\alpha_{12})}{Z_{12}}$$

$$I_{d1} = \frac{E_{d1}\cos\alpha_{11}}{Z_{11}} - \frac{E_{d2}\cos(\delta_{12}-\alpha_{12})}{Z_{12}}$$

$$I_1 = \sqrt{I_{q1}^2 + I_{d1}^2}$$
at an angle = $\tan^{-1} I_{d1}/I_{q1}$ (19)

and

$$I_{q2} = \frac{E_{d2}\sin\alpha_{22}}{Z_{22}} - \frac{E_{d1}\sin(\delta_{12}+\alpha_{12})}{Z_{12}}$$

$$I_{d2} = \frac{E_{d2}\cos\alpha_{22}}{Z_{22}} - \frac{E_{d1}\cos(\delta_{12}+\alpha_{12})}{Z_{12}}$$

$$I_2 = \sqrt{I_{q2}^2 + I_{d2}^2}$$
at an angle = $\tan^{-1} I_{d2}/I_{q2}$ (20)

It should be noted that the component currents refer to the axes of the particular machine considered, see figure 1.

Bibliography

1. STATIC STABILITY LIMITS AND THE INTERMEDIATE CONDENSER STATION, **C. F. Wagner** and **R. D. Evans**. AIEE TRANSACTIONS, volume 47, January 1928, pages 94–121; discussion, pages 121–3.

2. POWER LIMITS OF SYNCHRONOUS MACHINES, **Edith Clarke** and **R. G. Lorraine**. ELECTRICAL ENGINEERING, volume 52, November 1933, pages 780–7; discussion, March 1934, pages 475–7 and April 1934, page 602.

3. FIRST REPORT OF POWER SYSTEM STABILITY, report of subcommittee on interconnection and stability factors. ELECTRICAL ENGINEERING, volume 56, February 1937, pages 261–82.

4. TRANSMISSION LINE ENGINEERING (a book), **W. W. Lewis**. McGraw-Hill Book Company, New York, 1928, pages 275–327.

5. CALCULATION OF ALTERNATOR SWING CURVES —STEP-BY-STEP METHOD, **F. R. Longley**. AIEE TRANSACTIONS, volume 49, 1930, pages 1129–50; discussion, pages 1150–1.

6. SELECTED PROBLEMS ON PREDETERMINATION OF SYNCHRONOUS MACHINE PERFORMANCE, **C. F. Dalziel**. Thesis, University of California, 1935.

7. STEADY-STATE STABILITY OF COMPOSITE SYSTEMS, **S. B. Crary**. ELECTRICAL ENGINEERING, November 1933, pages 787–92; discussion, March 1934, pages 475–7.

8. THE SATURATED SYNCHRONOUS MACHINE, **B. L. Robertson, T. A. Rogers**, and **C. F. Dalziel**. ELECTRICAL ENGINEERING, volume 56, July 1937, pages 858–63; discussion, December 1937, pages 1502–3.

9. THE REACTANCE OF SYNCHRONOUS MACHINES, **R. H. Park** and **B. L. Robertson**. AIEE TRANSACTIONS, volume 47, April 1928, pages 514–35.

10. PROPOSED DEFINITIONS OF TERMS USED IN POWER SYSTEM STUDIES—Report of Subject Committee on Definitions, **H. K. Sels**. AIEE paper 32*M*-2, abstract ELECTRICAL ENGINEERING, volume 51, February 1932, page 106.

11. USE OF SYNCHRONOUS MACHINE QUANTITIES IN SYSTEM STUDIES, **W. M. Hanna**. *General Electric Review*, volume 36, March 1933, pages 116–28.

12. HETCH HETCHY, ITS ORIGIN AND HISTORY (a book), **M. M. O'Shaughnessy**. Recorder Printing and Publishing Company, San Francisco, 1934.

13. ENGINEERING FEATURES OF THE BOULDER DAM-LOS ANGELES LINES, **E. F. Scattergood**. AIEE TRANSACTIONS, May 1935, pages 494–512; discussion, February 1936, pages 200–04 and March 1936, page 282.

14. PROGRESS IN THE STUDY OF SYSTEM STABILITY, **I. H. Summers** and **J. B. McLure**. AIEE TRANSACTIONS, volume 49, January 1930, pages 132–58; discussion, pages 159–61.

Discussion

S. B. Crary (General Electric Company, Schenectady, N. Y.): The experimental checks which the author has obtained are very good and appear to substantiate his conclusion "that for practical purposes static stability may be regarded as a problem of stable equilibrium in which all transient phenomena and inertia effects may be neglected (reference 2)." However, as the author's experimental results necessarily only covered a very limited range, it is desirable to view any general conclusions drawn directly from such experiments quite critically. Mr. Dalziel's reference 2 presents a conservative method for determining the stability limit which has great practical value when applied with a knowledge of the conditions under which the results may be too conservative. Discussions of the limitations of the method may be found on pages 475, 476, 601, and 602, AIEE TRANSACTIONS, volume 53, 1934. An example of a case in which the inertia effects are important is a large generator delivering load to a large shunt load of constant impedance and a small synchronous motor. Actually the angular displacement between the motor and generator may approach 180 degrees with stable operation. Such a conclusion may be reached analytically when the relative inertia of the generator and motor are considered.

Reference is also made in the paper to the report of the AIEE subcommittee on stability (reference 3), to substantiate the contention that the inertia effects may be neglected. The subcommittee report must have been unintentionally misleading to the extent that it was possible for Mr. Dalziel to misinterpret it in this respect.

The following statement is made in the paper "For cases in which the system voltages are maintained constant, all shunt loads including synchronous condensers and induction motors may be accurately represented by simple shunt impedances. This treatment assumes that the induction portion of the system load remains stable. Since the maximum power transfer is ordinarily limited by the synchronous machine on the system, this assumption should not introduce errors in the result (reference 7)." That such a simplification cannot be made in many practical studies is well known and reference 7 does not show that this is possible. Reference 7 does show that a composite load may be replaced with good approximation by an equivalent load having a given real and reactive power and a given rate of change of real power and reactive power with voltage. These four characteristics are sufficient in order to obtain the effect of a composite load on the system. However, only when the rate of change of real and reactive power with respect to voltage are related to the total amount of real and reactive power in a definite manner can the composite load be replaced by a simple shunt impedance. This unfortunately is the exception rather than the rule. The case of fixed impedance load rather than the actual characteristics of a composite load will in general lead to optimistic or too high steady-state stability limits as the real power component of a composite load does not fall off or decrease as rapidly as that of a constant shunt impedance with drop in voltage.

A. J. Gilardi (Ohio Brass Company, Barberton): I should like to supplement Professor Dalziel's consideration of the Hetch Hetchy-Pacific Gas and Electric system by a concrete example which incidentally includes typical stability curves of the power system.

For accurate analysis equations 11 and 12 of the paper should be used to calculate the steady-state power limits. The steady-state power curve and margin of stability so determined accurately considers saliency and saturation. However, since the transmission line under consideration has considerable series impedance it will be sufficiently accurate to compute the steady-state power curve using $X_{q\ net}$ in equations 13 and 14. In figures 3 and 4 of the paper it is shown that the error due to neglecting saliency decreases with increased system impedance. The simplification obtained by neglecting saliency greatly reduces the labor of computation and the resulting errors are small. The steady-state power limits and stability coefficients computed using 0.90 $X_{q\ unsat}$ in determining S_1 and S_2 from equations 13 and 14 gives results which are approximately correct where accuracy is not essential (i.e., at the large margins of stability) and accurate results at the power limit where good accuracy is desired.

The accompanying figure 1 illustrates the power system under consideration, except that only one circuit of the transmission line was used in the computations. The receiving-end bus feeds a shunt load

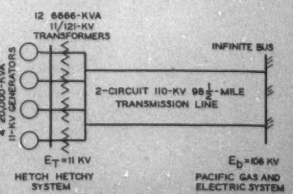


Figure 1. Hetch Hetchy-Pacific Gas and Electric interconnected system

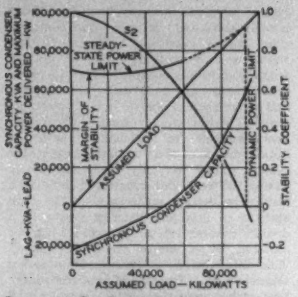


Figure 2. Steady-state and dynamic power limits of Hatch Hatchy system

and the synchronous condenser serves to maintain constant voltages on the system. The following equations were used to determine the stability limits utilizing the simplifications of the preceding paragraph:

$$P_1 = \frac{e_{g1}^2}{Z_{11}} \sin \alpha_{11} + \frac{e_{g1} E_b}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) \quad (1)$$

$$S_1 = \cos(\delta_{12} - \alpha_{12}) \quad (2)$$

$$P_2 = \frac{E_b^2 \sin \alpha_{22}}{Z_{22}} - \frac{e_{g1} E_b}{Z_{12}} \sin (\delta_{12} + \alpha_{12}) \quad (3)$$

$$S_2 = \cos (\delta_{12} + \alpha_{12}) \quad (4)$$

Since α_{12} is positive the power limits are determined by P_1 and S_2. The results of computations for various loads using the foregoing equations are shown in figure 2. These results were obtained using actual system constants with the exception of the generator reactances. The curve for S_1 is not shown since S_2 reaches zero first. The synchronous-condenser kilovolt-ampere curve indicates the amount of capacity required to maintain constant system voltage at any given load. It may be seen that the dynamic power limit is approximately 92,500 kw with one line in service. As mentioned in the paper one line has delivered approximately 77,000 kw during emergency switching and tripouts.

Figure 3 compares the margin of stability of figure 2 with that obtained for the same system using the unsaturated cylindrical-rotor theory. It is evident that the latter approach gives only an approximate solution which is less accurate than by using the theory outlined in the paper.

Charles F. Dalziel: The author wishes to thank S. B. Crary for the constructive comments drawn from his rich experience in this field. The final draft of the paper has been changed in an endeavor to meet his objections regarding the representation of loads. It was originally intended to check the method and the simplifying assumptions under question by comparing theoretical results with the operating records of several large power systems. The analyses of the practical problems presented in the paper are consistent and in good agreement with available operating

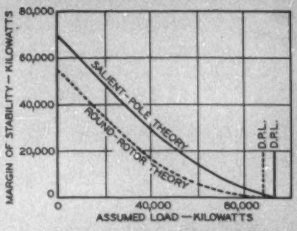


Figure 3. Comparison of results obtained by use of round-rotor or salient-pole theory

records. However, due to limited data, the results fall somewhat short of the original objective. The writer would appreciate receiving system data for cases where the stability limits are fairly accurately known, and which could be reduced to a two-generator system for analysis.

Mr. Gilardi's detailed analysis of the Hetch Hetchy system should be of interest to those applying the method to actual systems. It should be repeated that most of the generator impedances in the practical problems were unknown, and typical average values were used. These were multiplied by 0.90 to give an approximate correction for saturation. This may explain the small effect of saliency and saturation on Mr. Gilardi's power limits in contrast to the experimental differences of figure 8.

Applications of Copper-Oxide Rectifiers

By E. W. MORRIS
MEMBER AIEE

Synopsis: Since the development of the copper-oxide rectifier in 1927, no paper has presented to the Institute a comprehensive list of the many problems to which the device may be applied successfully. It is the purpose of this paper to describe a few of the representative installations made in the various industries.

WHEN the copper-oxide rectifier was announced,[1] limited information was available regarding such characteristics as aging, the effect of ambient temperatures, and the safe values of current and voltage per disk. Applications made since 1927 have removed many of these uncertainties. Continued research has produced valuable information about the characteristics of the device, and has improved the method of manufacture and application to industry.[2,3] It has become indispensable in the design of control and electronic equipment,[4] and is well adapted to applications requiring high efficiency at low voltage and to those requiring high overload capacities for short periods of time.

The copper-oxide rectifier consists essentially of a copper disk, one side of which is covered with cuprous oxide formed by heating to a high temperature. This rectifier disk then has the characteristics of asymmetric resistance, allowing electrons to pass more readily from copper to oxide than in the reverse direction, as indicated in figure 1. The rating of a disk is based upon ability to dissipate the losses, and rectifier disks usually are assembled into units with cooling fins and spacers to assist in heat dissipation. Soft metal washers insure intimate contact with the oxide.

These assembled units may be connected into groups for half- and full-wave rectification, for any number of phases, and in parallel or series for increased current or voltage ratings.

As valves in d-c control circuits they are convenient in isolation of circuits, preventing current flow in reverse directions to a common bus.

Applications of copper-oxide disks made during the past ten years can be classified as rectifiers for battery loads, rectifiers for resistance loads, and valves in control circuits.

I. Rectifiers for Battery Loads

After the development of the copper-oxide rectifier, one of the most immediate applications was that of small battery

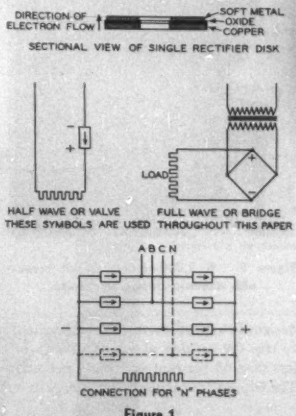


Figure 1

chargers. Sizes of chargers have gradually increased until now they are available in ratings up to 6 amperes at 130 volts. A duplex charger having a rating of 15 amperes at 30 volts and 0.5 ampere at 24 volts is shown in figure 2. Simplicity results in an assembly consisting of an insulating transformer, the copper-oxide rectifying units, some type of overload protection, and a dial switch to care for current adjustment and aging.

The nearest approach to an ideal battery charger has been obtained in the recent development of a self-regulating charger, the diagram of which is shown in figure 3. It is particularly adaptable for floating battery service, and automatically variest the charging rate proportionate with the demands of the battery by means of saturable reactors. The main rectifier, I, furnishes charging current to the battery. Between the transformer secondary and the main rectifier is located a saturable reactor, *A*. The saturation of reactor *A* is controlled partly by a series coil which is energized by the

Figure 2. Station-type rectifier for charging telephone batteries

charging current, partly by a shunt coil, but mainly by rectifier II. This rectifier is supplied from the primary side of the transformer through a second saturable reactor, *B*. Rectifier III is furnished with a constant a-c voltage by means of a small regulator connected across the primary of the power transformer. The constant d-c output voltage of rectifier III is opposed by the battery voltage so that any difference between the two will result in a flow of current through the d-c winding of reactor *B;* hence the saturation of reactor *B* will vary according to the battery voltage. Reduction in the cell

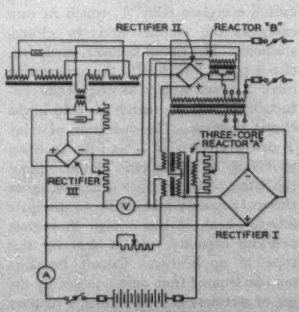


Figure 3. Automatic self-regulating battery charger

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1. For all numbered references, see list at end of paper.

voltage below the average for which the charger is set to regulate will cause the charger to turn on and deliver full charging current to the battery. As the cell voltage increases to a point above the average voltage, the charging current will be reduced to its minimum value. Such a charger is capable of maintaining the cell voltage within limits of plus or minus one per cent for all load conditions and for variations in the a-c line voltage of not more than plus or minus five per cent.

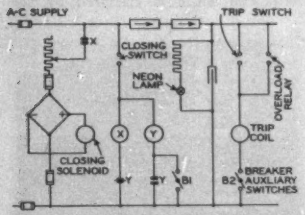

Figure 4. Circuit breaker closing and tripping from an a-c supply

II. Rectifiers for Resistance Loads

In the field of industrial control, versatility has been added by the use of the copper-oxide rectifier. The advantages of d-c operation of contactors and relays can be obtained from an a-c source and the rectifying units. D-c fields can be excited from an a-c supply and regulated by means of the proper arrangement of rectifiers and reactors.

Rectifiers for Circuit-Breaker Operation

Solenoid type of circuit-breaker mechanisms may be operated from an a-c source by means of rectifiers connected as in figure 4. Operation of the closing switch energizes relay *X*, which in turn energizes the rectifier and the closing solenoid. The circuit breaker, in closing, closes pallet switch *B*1, thus energizing relay *Y*, which seals in as long as the contacts of the closing switch are held in the closed position. The operation of relay *Y* de-energizes relay *X* and the rectifier, providing an automatic cutoff. Since the rating of the rectifier is limited by its thermal capacity and ability to dissipate internal heat, it has a high short-time overload capacity, and is ideal for this type of application. Circuit breakers may be tripped from an a-c source by the use of rectifiers and capacitors, a distinct advantage in the elimination of battery maintenance at isolated or unattended substations. Capacitor tripping has the advantage of requiring current transformers only of sufficient size to energize the fault-detector relays. The tripping energy is stored in capacitors from the a-c supply voltage during normal conditions, and is available to trip the breaker for at least six seconds after charging potential is entirely removed. In figure 4, when the overload relay or manual tripping contacts close, the capacitor discharges through the trip coil. The device is so designed that sufficient charge is available to trip the breaker at any time with not less than 65 per cent of normal potential. The tripping capacitor will recharge in 0.2 second. Figure 5 shows, in the lower left-hand corner, the small size of rectifier required to close a 5,000-ampere three-pole air circuit breaker.

Figure 5. A 5,000-ampere circuit breaker with solenoid closing mechanism

Figure 6. Voltage regulator for a-c generator

Voltage Regulators for A-C Generators

It has long been recognized that a-c generators inherently have a poor regulation, lacking the advantage of a series field for maintaining a nearly constant voltage under varying loads. The device shown in figure 6 was developed to meet the demand for a simple voltage regulator, with no moving parts, for small-size a-c generators. It consists of copper-oxide rectifier units assembled with the proper transformers, reactors, and resistors to provide an increase in the exciter shunt-field current proportional to the increase in voltage required under varying loads on the generator. As indicated in figure 7, changes in generator load are reflected in two full-wave rectifier units. Rectifier I is energized by a current transformer, and is adjusted to produce a compounding effect to some voltage less than normal at full load. Rectifier II, energized from

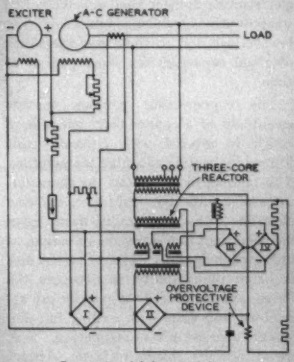

Figure 7. Voltageregulator

the generator potential, supplies the additional rectified field current necessary for maintaining normal generated voltage. A small change from normal potential on the circuits of rectifiers III and IV causes a relatively large change in the output of the three-core reactor in series with rectifier II.

Under normal conditions of operation, this type of regulator will maintain the voltage within plus or minus three per cent from no load to full load.

Another simple form of a-c regulator is shown in figure 8, this requiring special design of the generator and exciter fields

Rectifiers for the Prevention of Electrolysis

Corrosion of underground structures can be mitigated by the use of cathodic protection, and is conveniently accomplished by connecting the underground structure to the negative terminal of a d-c source and by maintaining it negative to the earth by 0.3 volt or greater. Corrosion occurs in underground structures due to stray currents from d-c systems, and from electrochemical reactions between the structure and the surrounding soil. Small currents flow from the underground structure through the soil to other parts of the structure, corrosion occurring where the currents leave the structure. Figure 9 shows an outdoor installation of a rectifier unit rated 30 amperes at ten volts, used to protect a section of a pipe line from corrosion. The use of the copper-oxide rectifier for this d-c supply is preferred to other d-c sources, because of its efficiency at low voltage and the fact that a minimum of maintenance is required, such as an occasional check of the output to adjust for seasonal variations

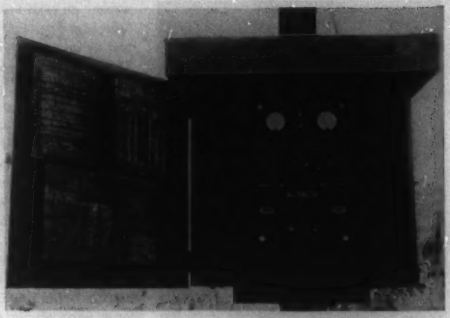

Figure 9. Installation of rectifier for protection against electrolysis on pipe line

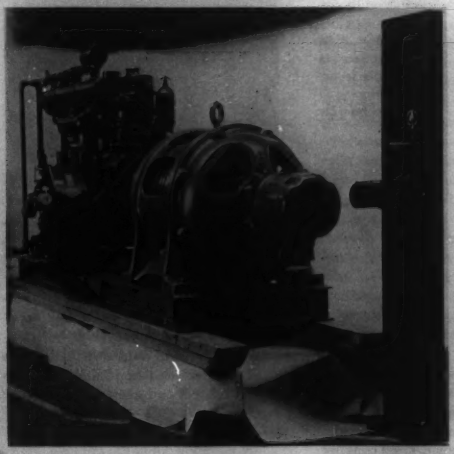

Figure 8. The rectifiers on this switchboard provide voltage regulation for the large engine-driven a-c generator

in the soil. The device is noiseless and free from radio interference, factors which are important when the device must be located in residential districts. The schematic diagram in figure 10 indicates how this type of device is connected to protect a section of pipe against corrosion.

III. Valves in Control Circuits

The asymmetric resistance characteristics of this rectifier makes it particularly suitable as a valve to control the path of flow of direct current. This type of application has increased the versatility of control circuits and has reduced the number of mechanical relays necessary to complete many control functions. This is best illustrated by a few of the examples given in figure 11.

Remote control of many devices may be accomplished in a minimum time by the system of polarized lines, shown for two wires in figure 11*A*. Relay *A* or *B* will operate depending on the relative polarities of the bus to which they are connected. This simple two-conductor system may be arranged to operate over one conductor and a good ground return such as a water pipe, which is sometimes convenient in the remote control of pumping plants. By the use of three or more wires the number of relays that can be operated increases[6] because of the many possible combinations of polarized lines.

The rectifier valve has become quite useful in isolating the flow of direct current within parts of a circuit, as shown in figure 11*B*. This shows a system of relays and rectifier valves, each of which may be energized either from a common test bus or through contacts on alarm devices. Each alarm contact allows but one relay to operate, the valve in that circuit preventing current flow to the test bus and to other relays. The circuit, and all signal lamps, may be checked conveniently by depressing the test button, wherein all of the relays are energized simultaneously. Figure 12 illustrates a group of rectifier valves and relays used

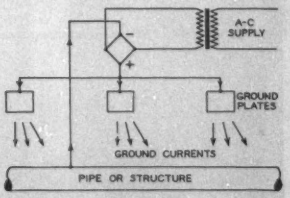

Figure 10. Cathodic protection against electrolysis

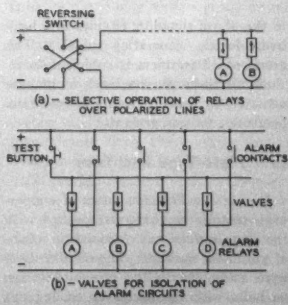

Figure 11

Figure 12. Valve-type rectifiers installed in annunciator circuits (cover removed from one group only)

washer on each bolt was tightened to obtain high contact pressure between the soft metal washers and the oxide surfaces. The size of disks was limited to a diameter of $1^1/_2$ inches by the ability to maintain uniform pressure over the entire surface.

Continued research during that time developed a satisfactory method of spraying a conducting coating on large copper-oxide plates.[4] The necessity for high contact pressure having been removed, the new rectifier plates with sprayed coating are assembled a fraction of an inch apart and the losses are dissipated by means of forced air. Electrical connections between plates are made with clips. Four sizes of plates, 10 inches and 12 inches in length, and 3 inches and $4^3/_8$ inches in width, have been used in group assemblies. The rating in output of a three- by ten-inch plate assembled in a properly ventilated, three-phase rectifier, is 20 watts at six volts d-c maximum. A complete three-phase full-wave rectifier which would require six plates, would then have an output rating of 120 watts at six volts, or 20 amperes, six volts d-c maximum. In the larger plates current capacity increases in proportion to the area, but the voltage rating remains the same. The plates can of course be connected in series or parallel, to any desired capacity. The development of the plate-type copper-oxide rectifier will not supplant, but will supplement, the standard design disk assemblies, and will increase the number of applications in the high-current low-voltage field.

Figure 13. Plate-type rectifiers installed in film laboratory for stripping silver from film

in the alarm signaling circuits of a large hydroelectric generating plant. This group of 16 rectifiers is sufficient to include all alarm devices, such as may be actuated by bearing, coil, and core temperatures, for one generator.

IV. Plate-Type Rectifiers

During the first ten years of copper-oxide-rectifier manufacture, contact with the oxide surface was obtained by means of soft metal washers. The rectifier disks were assembled in the proper direction on bolts with the necessary cooling fins and spacers. A special cupped spring

The major field for such units, is in the electrochemical industry, including, for example, chemical processing, electrolytic cleaning, and electroplating. Figure 13 shows an installation of two plate-type rectifiers each rated four volts, 200 amperes d-c output at 220 volts, three-phase, 60 cycles, a-c input. These are installed in a laboratory for use in stripping silver from salvaged film. Figure 14 shows a large-capacity plate-type rectifier. This rectifier has an output rating of 1,500 amperes, six volts maximum for 220 volts, three-phase, 60 cycles, a-c input.

Conclusions

No attempt has been made herein to list all possible applications, but to describe a few representative types and to show installation photographs of rectifiers in new kinds of services. Units have been assembled with ratings which vary from

Figure 14. Plate-type rectifier, 1,500 amperes, 6 volts d-c output, built for electroplating service

0.001 watt to several kilowatts in capacity. This is a device which finds applications in any field, whether it be transportation, power, or industry. The future should see increased application for simplifying control and metering problems.

References

1. A New Electronic Rectifier, L. O. Grondahl and P. H. Geiger. AIEE Transactions, February 1927.

2. Characteristics and Applications of the Copper-Oxide Rectifier, C. E. Hamann and E. A. Harty. *General Electric Review*, August 1933.

3. Copper-Oxide Rectifiers for Motion-Picture Arc Supply, I. R. Smith. *Journal* of the Society of Motion Picture Engineers, September 1936.

4. Industrial Electronic Control Applications, F. H. Gulliksen and R. N. Stoddard. Electrical Engineering (AIEE Transactions) January 1935.

5. Split-Second Supervisory Control, M. E. Reagan. *Electric Journal*, June 1932.

6. The Rectox Rectifier Grows, I. R. Smith. *Electric Journal*, May 1937.

The Electrostatic Unbalance of Transmission Lines and Its Effect on the Application of Petersen Coils

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RECENTLY three Petersen coils were installed on the 66-kv transmission system of the Metropolitan Edison Company of Pennsylvania. These Petersen coils provide service protection to approximately 320 miles of overhead transmission lines against outages and voltage dips which would otherwise result when single phase-to-ground flashovers occur on the system. Much of the 66-kv transmission system consists of two-circuit lines with vertical configurations of the line conductors with no transpositions prior to the Petersen-coil installation.

During the tuning tests on these Petersen coils which were made before putting them in service, it was found that excessive currents were flowing through the coils when tuned with the system, even though there was no ground fault on the system. These currents far exceeded the continuous current ratings of the coils, and they were of such magnitude that the system neutral in some cases shifted as much as 70 per cent above ground. The shift in the neutral above ground, if allowed to remain on the system, would have needlessly subjected the line insulation and connected apparatus to dynamic overvoltages. Accordingly, an investigation was made to determine the cause of this excessive current.

Measurements obtained of the line-to-ground voltages with the system neutral isolated revealed an abnormally unbalanced capacity to ground. That is, the capacities to ground of the three phases were unequal, causing unequal voltages and, therefore, with the Petersen coils in the neutral, excessive current flowed. The unbalanced capacity was accounted for by the lack of transpositions in the transmission lines. It became apparent that by rearranging some of the circuits, the direct capacities of the three phases to ground could be balanced and the circulating current passing through the Petersen coils would be reduced to a small fraction of its original value.

This paper deals with the analysis of zero-sequence electrostatic unbalance of transmission lines to neutral, illustrates the methods of calculation, applies these calculations to obtain a proper balance in the most economical manner, and presents experimental data which verify the methods and procedure used for the solution of the problem. The subject of electrostatics is considered not in its entirety, but only to the extent necessary for the application of impedors (also grounding transformers and neutral reactors). It is hoped that the information embodied in this paper may be of use to others contemplating the use of Petersen coils, neutral reactors, or grounding transformers. The material which follows should not be construed as an attempt to add to the subject of electrostatics; it is instead the application of well-known fundamentals to a very practical situation. For this reason there is at the conclusion of the text a list of general references which contain all of the necessary theory and methods which are used herein.

Briefly, a Petersen coil is an iron-core variable inductance which, when system leg voltage is applied across it, passes a current the magnitude of which is equal to the charging current in a line-to-ground fault on the system when the system neutral is isolated. During the occurrence of a single line-to-ground fault, the Petersen coil causes the flow of a reactive current which is equal to and 180 degrees out of phase with the capacitive current which flows in the ground fault. The result is that the current in the arc is reduced to very nearly zero, the arc is extinguished, and the temporary ground fault disappears without having become a permanent ground fault or having developed into a line-to-line fault as is so often the case. The coil operation does not compensate for the small amount of in-phase or loss current which is usually present in the arc. In practice the current from these two sources is small and not sufficient to maintain the arc. Owing to the fact that a perfect electrostatic balance cannot be obtained practically, it is to be expected that some current will flow through the coil with system normal. This has been the case in previous installations. This flow of current does not interfere with the functioning of the coil in arc extinction in any practical case; the main objection to it, if it exists to an abnormal degree, is that of neutral displacement.

Figure 1 shows the schematic diagram of an impedor applied to a transmission line. The capacitance values of the line are shown as lumped constants in this diagram, and zero-sequence capacitance will be considered in this manner throughout the discussion. This can be done with impunity because in the application of impedors one is concerned primarily with the parallel circuit constants of the lines; the series reactance and resistance of the transmission lines are neglected in the analysis which follows. In the case of an actual transmission system, there will be a coil placed in the neutral of every ground bank, or a coil may serve a group of two or more ground banks. In some instances it may be desirable to separate a ground bank from ground completely and thereby save the cost of an additional coil. Of course, a Petersen-coil-protected system must be electrically insulated by transformers from every other system which is either grounded or ungrounded.

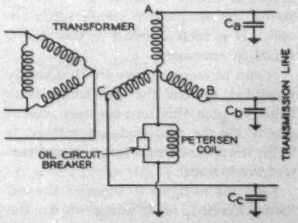

Figure 1. A Petersen coil applied to a transmission line

On the Metropolitan Edison Company system a coil was used at each of the three grounding banks which were originally chosen for number and positions according to relaying and switching requirements. It is desirable, when a system is operating in sections, that each section should be able to operate alone

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with Petersen-coil protection. The analysis loses none of its generality through the consideration of only one coil, and the reader is referred to the general theory on coil operation found in the list of references on that subject.

Now the installation of a coil upon a transmission system requires that the coil be tuned for the transmission lines which it is to protect; the coil must be tuned and set at a different tap when additional miles of line are added to the number which it must protect, or when the number of miles which it protects is reduced, such as in switching operations. This tuning process, varying the inductance by means of taps, corresponds to obtaining the resonance point for a simple series circuit. The tuning is accomplished while the transmission lines are operating under normal conditions without the presence of a ground fault. This is one of the several possible methods of tuning. For a given length of line, the tuned point is found when the tap setting, which corresponds to the maximum residual ground current, is obtained.

Figure 2 illustrates the electrical circuit. One tunes, of course, the zero-sequence circuit of figure 2. Figure 3 shows the comparable simple series circuit. It is such a circuit as this that is tuned to resonance.

It can be seen that even with a solidly grounded system the grounding bank helps to tune this zero-sequence circuit and if E_0, the zero-sequence voltage, is large, it appears that a large ground current would result.

Referring to figure 3, consider the coil short circuited, or in other words, the system is to be solidly grounded

Let

I_0 = zero-sequence component of phase current

I_n = current through neutral of ground bank

X_t = zero-sequence reactance of transformer

$X_{cap.}$ = average line-to-neutral zero-sequence capacitive reactance

R_g = equivalent ground resistance for entire circuit

X_{cl} = zero-sequence reactance of coil

Then:

$$I_n = 3I_0 = 3\frac{E_0}{3R_g + jX_t - jX_{cap.}}$$

Even when solidly grounded, the ground banks of the Metropolitan Edison Company had heavy ground currents. The reason for this was a large E_0 which was caused by the electrostatic or capacitive unbalance of the three lines to ground.

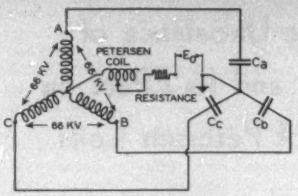


Figure 2. The three-phase circuit of a Petersen-coil installation

Now when the impedor is in the neutral of the ground bank, the current becomes:

$$I_n = 3I_0 = 3\frac{E_0}{3R_g + jX_t + jX_{cl} - jX_{cap.}}$$

The coil is in tune for the transmission system when X_{cl} is of such value that

$$X_t + X_{cl} = X_{cap.}$$

and this leaves the resistance R_g as the only factor limiting the current for a given voltage.

In tuning on the Metropolitan Edison system, the residual ground current increased on the resonance peak to as much as five times the continuous current rating of the Petersen coil. Obviously, the coils could not be put in service under such conditions.

In the haste to place the coils into operation during the lightning season, a futile attempt was made to achieve electrostatic balance by interchanging the top and bottom phases of a section of vertically spaced line. It is shown in the analysis to follow that for vertical construction, the top and bottom wires have higher capacitances than the middle wire which was left unchanged. In all of the work the effect of grounded crossarms and poles was neglected.

Vertical construction is used predominately on the lines of the Metropolitan Edison Company, although it has been found that all of the other types of construction, double and single lines, resulted in capacitive unbalance which was appreciable. The system under consideration was almost completely untransposed and this led, of course, to the resultant state of unbalance.

There follows the analysis applied to a typical transmission line as shown in figure 4.

Let

r = radius of conductors in inches

Q_a, Q_b, etc. = charge on conductors A, B, etc., in statcoulombs per centimeter

E_a, E_b, etc. = voltage above ground of conductors A, B, etc.

C_a, C_b, etc. = capacity of respective conductors to ground

Then using the method of images (Attwood, "Electric and Magnetic Fields," page 113) one obtains the following:

$$E_a = 2\left(Q_a \log_e \frac{2ag}{r} + Q_b \log_e \frac{ab'}{ab} + Q_c \log_e \frac{ca'}{ca}\right) \quad (1)$$

$$E_b = 2\left(Q_a \log_e \frac{ab'}{ab} + Q_b \log_e \frac{2bg}{r} + Q_c \log_e \frac{ca'}{ca}\right) \quad (2)$$

$$E_c = 2\left(Q_a \log_e \frac{ca'}{ca} + Q_b \log_e \frac{bc'}{bc} + Q_c \log_e \frac{2cg}{r}\right) \quad (3)$$

Similar equations may be written for any number of conductors. Now in general:

$$C\ (\text{Capacity}) = \frac{Q\ (\text{Charge})}{E\ (\text{Voltage})} \quad (4)$$

The direct or zero-sequence capacitance of a conductor A to ground is the ratio of the charge on conductor A to its potential (the zero-sequence potential) when all other conductors except the reference conductor, in this case the ground, are at the potential (zero-sequence potential) of A. Solving equations 1 to 3 would give equations for Q_a, Q_b, and Q_c in terms of V_a, V_b, and V_c. The three wires are allowed to assume the same potential with respect to ground; that is, $V_a = V_b = V_c$. It is thus possible to solve by the method of determinants equations 1, 2, and 3 for Q_a, and by dividing through by V_a, according to equation 4, the coefficients V_a, V_b, and V_c are removed from the expression which now represents the capacitance, C_a.

$$C_a = \frac{\begin{vmatrix} 1 & 2\log_e \frac{ab'}{ab} & 2\log_e \frac{ca'}{ca} \\ 1 & 2\log_e \frac{2bg}{r} & 2\log_e \frac{bc'}{bc} \\ 1 & 2\log_e \frac{bc'}{bc} & 2\log_e \frac{2cg}{r} \end{vmatrix}}{\begin{vmatrix} 2\log_e \frac{2ag}{r} & 2\log_e \frac{ab'}{ab} & 2\log_e \frac{ca'}{ca} \\ 2\log_e \frac{ab'}{ab} & 2\log_e \frac{2bg}{r} & 2\log_e \frac{bc'}{bc} \\ 2\log_e \frac{ca'}{ca} & 2\log_e \frac{bc'}{bc} & 2\log_e \frac{2cg}{r} \end{vmatrix}} \text{ statfarads per centimeter} \quad (5)$$

Expressions can likewise be found for C_b and C_c.

It is more convenient for computation to use logarithms to the base 10, and to obtain capacitance in microfarads per mile; thus equations 6, 7, and 8 arise.

$$C_a = 0.0389 \times \frac{\begin{vmatrix} 1 & \log \frac{ab'}{ab} & \log \frac{ca'}{ca} \\ 1 & \log \frac{2bg}{r} & \log \frac{bc'}{bc} \\ 1 & \log \frac{bc'}{bc} & \log \frac{2cg}{r} \end{vmatrix}}{\begin{vmatrix} \log \frac{2ag}{r} & \log \frac{ab'}{ab} & \log \frac{ca'}{ca} \\ \log \frac{ab'}{ab} & \log \frac{2bg}{r} & \log \frac{bc'}{bc} \\ \log \frac{ca'}{ca} & \log \frac{bc'}{bc} & \log \frac{2cg}{r} \end{vmatrix}}$$

microfarads per mile (6)

The denominators of 6, 7, and 8 are the same and can be denoted in each case by the symbol D.

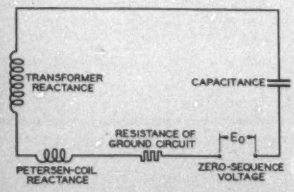


Figure 3. The equivalent zero-sequence resonant circuit

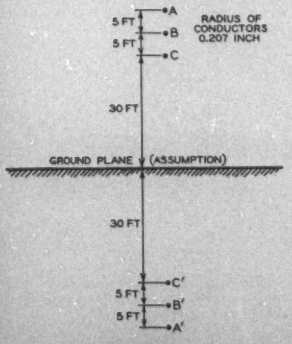


Figure 4. The transmission line spacings used in the calculations

$$C_b = 0.0389 \times \frac{\begin{vmatrix} \log \frac{2ag}{r} & 1 & \log \frac{ca'}{ca} \\ \log \frac{ab'}{ab} & 1 & \log \frac{bc'}{bc} \\ \log \frac{ca'}{ca} & 1 & \log \frac{2cg}{r} \end{vmatrix}}{D}$$

microfarads per mile (7)

$$C_c = 0.0389 \times \frac{\begin{vmatrix} \log \frac{2ag}{r} & \log \frac{ab'}{ab} & 1 \\ \log \frac{ab'}{ab} & \log \frac{2bg}{r} & 1 \\ \log \frac{ca'}{ca} & \log \frac{bc'}{bc} & 1 \end{vmatrix}}{D}$$

microfarads per mile (8)

Solving for the capacitances of the line of figure 4:

$$\log \frac{2ag}{r} = \log \frac{12 \times 2 \times 40}{0.207} = 3.666$$

$$\log \frac{2bg}{r} = \log \frac{12 \times 2 \times 35}{0.207} = 3.609$$

$$\log \frac{2cg}{r} = \log \frac{12 \times 2 \times 30}{0.207} = 3.541$$

$$\log \frac{ab'}{ab} = \log \frac{75}{5} = 1.176$$

$$\log \frac{ca'}{ca} = \log \frac{70}{10} = 0.846$$

$$\log \frac{bc'}{bc} = \log \frac{65}{5} = 1.114$$

$$D = \begin{vmatrix} 3.666 & 1.176 & 0.846 \\ 1.176 & 3.609 & 1.114 \\ 0.846 & 1.114 & 3.541 \end{vmatrix} = 37.08$$

$$(C_a \times D) = 0.0389 \times \begin{vmatrix} 1 & 1.176 & 0.846 \\ 1 & 3.609 & 1.114 \\ 1 & 1.114 & 3.541 \end{vmatrix}$$

$$= 0.0389 \times 6.523$$

$$C_a = \frac{(C_a \times D)}{D} = 0.0389 \times \frac{6.523}{37.08}$$

$$= 0.00685 \text{ microfarad per mile}$$

$$(C_b \times D) = 0.0389 \times \begin{vmatrix} 3.666 & 1 & 0.846 \\ 1.176 & 1 & 1.114 \\ 0.846 & 1 & 3.541 \end{vmatrix}$$

$$= 0.0389 \times 5.962$$

$$C_b = \frac{(C_b \times D)}{D} = \frac{0.0389 \times 5.962}{37.08}$$

$$= 0.00625 \text{ microfarad per mile}$$

$$(C_c \times D) = 0.0389 \times \begin{vmatrix} 3.666 & 1.176 & 1 \\ 1.176 & 3.609 & 1 \\ 0.846 & 1.114 & 1 \end{vmatrix}$$

$$= 0.0389 \times 7.028$$

$$C_c = \frac{(C_c \times D)}{D} = \frac{0.0389 \times 7.028}{37.08}$$

$$= 0.00737 \text{ microfarad per mile}$$

It is the problem now to show that such an electrostatic unbalance to neutral as indicated by the zero-sequence capacitance values above can produce a large E_0, or zero-sequence voltage, which is responsible for the large residual currents. In this computation, it makes no difference whether one considers one mile or 100 miles of line having the per mile capacitance values which have just been found.

Therefore:

$$X_a = \frac{-j}{2\pi f C_a} = \frac{-j}{377 \times 0.00685 \times 10^{-6}}$$

$$= -j387{,}000 \text{ ohms}$$

NOTE: The letter f designates frequency in the above expression

$$X_b = \frac{-j}{2\pi f C_b} = \frac{-j}{377 \times 0.00625 \times 10^{-6}}$$

$$= -j424{,}000 \text{ ohms}$$

$$X_c = \frac{-j}{2\pi f C_c} = \frac{-j}{377 \times 0.00737 \times 10^{-6}}$$

$$= -j360{,}000 \text{ ohms}$$

Now these zero-sequence capacitive reactances are considered as forming an unsymmetrical wye load with balanced line-to-line voltages of 66,000 volts. The method of symmetrical components with the usual notation is used.

$$X_0 = 1/3\,(X_a + X_b + X_c)$$

$$= \frac{-j}{3}\,(387{,}000 + 424{,}000 + 360{,}000) \text{ ohms}$$

$$= -j390{,}000 \text{ ohms} = -j390 \times 1{,}000 \text{ ohms}$$

$$X_1 = 1/3\,(X_a + aX_b + a^2X_c)$$

$$= 1/3\{-j387{,}000 - j424{,}000\,(-0.5 + j0.866) - j360{,}000\,(-0.5 - j0.866)\} \text{ ohms}$$

$$= (18.3 + j2) \times 1{,}000 \text{ ohms}$$

$$X_2 = 1/3\,(X_a + a^2X_b + aX_c)$$

$$= 1/3\{(-j387{,}000 - j424{,}000\,(-0.5 + j0.866) - j360{,}000\,(-0.5 - j0.866)\} \text{ ohms}$$

$$= (-18.3 + j2) \times 1{,}000 \text{ ohms}$$

Now

$$E_0 = I_1X_2 + I_2X_1 \quad (9)$$

$$E_1 = I_1X_0 + I_2X_2 \quad (10)$$

$$E_2 = I_2X_0 + I_1X_1 \quad (11)$$

$$E_1 = \frac{66{,}000}{\sqrt{3}} = 38{,}100 \text{ volts (phase voltage effective value)}$$

$E_2 = 0$ (not generated)

Using equation 10 there results:

$$38{,}100 = I_1\,(-j390{,}000) + I_2\,(-18.3 + j2) \times 1000$$

or

$$38.1 = I_1\,(-j390) + I_2\,(-18.3 + j2) \quad (12)$$

Using equation 11

$$0 = I_1(-j390{,}000) + I_1(18.3 + j2) \times 1{,}000$$
$$0 = I_1(-j390) + I_1(18.3 + j2) \qquad (13)$$

Remembering that I_1 and I_2 are vectors, one can obtain four linear simultaneous algebraic equations from (12) and (13), and these can be solved for I_1 and I_2 which are found to be:

$$I_1 = 0.000735 + j0.0979$$
$$I_2 = 0.00459 - j0.000735$$

Substituting these values in (9), it follows:

$$V_0 = (0.000735 + j0.0979)(-18.3 + j2) \times 1000 + (0.00459 - j0.000502) \times (18.3 + j2) \times 1000$$
$$V_0 = -125.25 - j1799.1$$

Absolute value of V_0 = 1,800 volts (effective value) (14)

In an actual test at the West Reading plant of the Metropolitan Edison Company it was found that 57 miles of line having the dimensions and construction which have just been considered operated with a zero-sequence voltage or neutral displacement voltage of 1,920 volts. This checks very closely with the value of 1,800 volts from the computations; it should be obvious that any discrepancy which is present can be attributed to the sag in the lines and other immeasurable irregularities in the lines. Furthermore, the computations have involved the assumption of the plane of zero potential or ground plane.

Transpositions were made at the regular switching stations or accessible H-frame structures of the above system for the 57 miles considered and as a result the displacement voltage was reduced to 144 volts. With this voltage even under conditions of resonance the Petersen coils could operate safely within their continuous ratings.

It should be pointed out that zero-sequence electrostatic balance to neutral can be and was obtained in actual practice, both by completely transposing as well as by interchanging two of the three line wires.

Refer to figure 4.

C_a = 0.00685 microfarad per mile
C_b = 0.00625 microfarad per mile
C_c = 0.00737 microfarad per mile

The arithmetical mean of C_b and C_c is 0.00681 microfarad per mile. Thus it can be seen that if A phase is always on top, B phase is half of the distance in the middle and the other half of this distance on the bottom, and C phase is half of the distance on the bottom and the other half of the distance in the middle position, an almost perfect balance of capacities to neutral is obtained.

Economic considerations were important in the revision of the existing transmission lines of the Metropolitan Edison Company. Transpositions were confined to switching stations or other accessible points such as H-frame locations; no new structures were erected. In some instances one line was arranged so as to electrostatically balance a second line, although an outage of either line would cause the line remaining in service to throw some unbalance on the system. There are several instances on the system of balancing one line against one or more lines. However, the system is large enough so that two or three line outages may occur without causing a prohibitive residual current, assuming, of course, that the coils have been retuned for the new system setup. In some very remote conditions of operation, the coils will have to be detuned or else taken out of service completely by short-circuiting them, which is equivalent to solidly grounding the transformer banks.

It seems necessary to add that in some instances the capacitances of the line insulators will be an important factor in the electrostatic unbalance to neutral. The capacitance of an individual pin-type insulator may be as high as 60 micro-microfarads. With bonded and grounded hardware the added balanced capacitance of the insulators could conceivably reduce the displacement voltage by ten per cent.

Obviously, the method of obtaining the direct capacitances to neutral of the line conductors can be extended to apply for transmission lines having one or more ground wires; double lines with or without ground wires yield also to this method. The equations for capacitances of double transmission lines with two ground wires are given in the appendix. Calculations involving all of these possibilities were made for the Metropolitan Edison Company system and the results were checked in the field; an accuracy was obtained in all cases comparable to the case which has just been considered in detail.

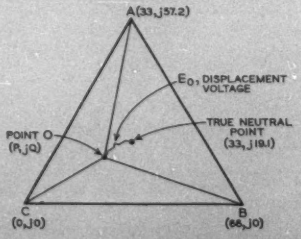


Figure 5. Potential diagram which applies to the method of the appendix

Appendix

The following alternative method is given for obtaining the displacement voltage E_0. It is especially useful for those who are unfamiliar with the symmetrical-component notation.

Figure 5 shows the potential diagram for three equal line voltages drawn in the complex domain. The line-to-line voltage is 66,000 volts. The co-ordinates in figure 5 are given in thousands of volts.

Let

E_{ao}, E_{bo}, and E_{co} = the voltages from O to A, B, and C, respectively, expressed in thousands of volts

As before

$X_a = -j387{,}000$ ohms
$X_b = -j424{,}000$ ohms
$X_c = -j360{,}000$ ohms

Now

$$E_{ao} = 33 - P + j57.2 - jQ$$
$$E_{bo} = 66 - P + j0 - jQ$$
$$E_{co} = 0 - P + j0 - jQ$$

The above equations express the line-to-neutral voltages in terms of the co-ordinates of the complex number system.

If it is assumed that the direction of the line currents I_a, I_b, and I_c is such that they all flow toward the neutral point O, then:

$$I_a + I_b + I_c = 0 \qquad (15)$$

Now

$$I_a = \frac{E_{ao}}{X_a}$$
$$I_b = \frac{E_{bo}}{X_b}$$
$$I_c = \frac{E_{co}}{X_c}$$

These three currents will be in amperes if X_a, X_b, and X_c are in thousands of ohms, for the voltages are expressed in thousands of volts.

$$I_a = \frac{33 - P + j57.2 - jQ}{-j387}$$
$$= j0.0852 - j0.00258P - 0.1475 + 0.00258Q \qquad (16)$$

$$I_b = \frac{66 - P - jQ}{-j424}$$
$$= j0.1557 - j0.00236P + 0.00236Q \qquad (17)$$

$$I_c = \frac{-P - jQ}{-j360}$$
$$= -j0.00278P + 0.00278Q \qquad (18)$$

Then substituting the values of the currents from equations 16, 17, and 18 in equation 15 there is produced (19).

$$j0.0852 - j0.00258P - 0.1475 + 0.00258Q + j0.1557 - j0.00236P + 0.00236Q - j0.00278P + 0.00278Q = 0 \qquad (19)$$

Now the algebraic sum of the terms directed along the axis of reals may be equated to zero.

$$-0.1475 + 0.00258Q + 0.00236Q + 0.00278Q = 0 \quad (20)$$
$$0.00772Q = 0.1475$$
$$Q = 19.1$$

Similarly the algebraic sum of the terms directed along the axis of imaginaries may be equated to zero.

$$j0.0852 - j0.00258P + j0.1557 - j0.00236P - j0.00278P = 0 \quad (21)$$
$$0.00772P = 0.2409$$
$$P = 31.2$$

From figure 5 the co-ordinates of the true neutral are 33, $j19.1$. Now E_0 is the zero-sequence voltage or the displacement voltage from true neutral.

$$E_0 = \sqrt{(19.1 - Q)^2 + (33 - P)^2}$$
$$= \sqrt{(19.1 - 19.1)^2 + (33 - 31.2)^2}$$
$$= 1.8 \text{ thousands of volts}$$
$$E_0 = 1{,}800 \text{ volts} \quad (22)$$

This value of the residual voltage agrees with the value obtained by the first method.

The direct capacitances for a double-circuit transmission line with two ground wires can be found by writing equations similar to (1), (2), and (3) and proceeding as for the single-circuit three-wire line. Let A, B, and C represent the conductors for one circuit; D, E, and F will represent the conductors for a second circuit; M and N will represent two ground wires; and r_a, r_b, r_c, r_d, r_e, r_f, r_m, r_n will represent radii of the respective conductors. Then ag will be the distance of conductor A to ground. The expression ab' will represent the distance from A to the image B' of B, and ab will represent the distance from A to B. The same system will apply to all conductor distances.

There follows a list of terms which must be computed. The logarithms are to be taken using the base 10.

$$P_{aa} = \log \frac{2ag}{r_a} \qquad P_{bd} = \log \frac{bd'}{bd}$$
$$P_{ab} = \log \frac{ab'}{ab} \qquad P_{be} = \log \frac{be'}{be}$$
$$P_{ac} = \log \frac{ac'}{ac} \qquad P_{bf} = \log \frac{bf'}{bf}$$
$$P_{ad} = \log \frac{ad'}{ad} \qquad P_{bm} = \log \frac{bm'}{bm}$$
$$P_{ae} = \log \frac{ae'}{ae} \qquad P_{bn} = \log \frac{bn'}{bn}$$
$$P_{af} = \log \frac{af'}{af} \qquad P_{cc} = \log \frac{2cg}{r_c}$$
$$P_{am} = \log \frac{am'}{am} \qquad P_{cd} = \log \frac{cd'}{cd}$$
$$P_{an} = \log \frac{an'}{an} \qquad P_{ce} = \log \frac{ce'}{ce}$$
$$P_{bb} = \log \frac{2bg}{r_b} \qquad P_{cf} = \log \frac{cf'}{cf}$$
$$P_{bc} = \log \frac{bc'}{bc} \qquad P_{cm} = \log \frac{cm'}{cm}$$
$$P_{cn} = \log \frac{cn'}{cn} \qquad P_{em} = \log \frac{em'}{em}$$
$$P_{dd} = \log \frac{2dg}{r_d} \qquad P_{en} = \log \frac{en'}{en}$$
$$P_{de} = \log \frac{de'}{de} \qquad P_{ff} = \log \frac{2fg}{r_f}$$
$$P_{df} = \log \frac{df'}{df} \qquad P_{fm} = \log \frac{fm'}{fm}$$
$$P_{dm} = \log \frac{dm'}{dm} \qquad P_{fn} = \log \frac{fn'}{fn}$$
$$P_{dn} = \log \frac{dn'}{dn} \qquad P_{mm} = \log \frac{2mg}{r_m}$$
$$P_{ee} = \log \frac{2eg}{r_e} \qquad P_{mn} = \log \frac{mn'}{mn}$$
$$P_{ef} = \log \frac{ef'}{ef} \qquad P_{nn} = \log \frac{2ng}{r_n}$$

Equation 23 gives the value of the capacitance of conductor A. Equation 24, which has the same denominator T as equation 23, gives the value of the capacitance of conductor B. If the column of six one's and two zero's successively replaces in the numerator the A column (farthest left), and the B, C, D, E, F, M, and N columns, expressions will be obtained for the capacitances of A, B, C, D, E, F, M, and N conductors in the order named. Equation 23 has the replacement in the A column; equation 24 in the B column. The same denominator T is used for all of the expressions.

$$C_a = 0.0389 \times \frac{\begin{vmatrix} 1 & P_{ab} & P_{ac} & P_{ad} & P_{ae} & P_{af} & P_{am} & P_{an} \\ 1 & P_{bb} & P_{bc} & P_{bd} & P_{be} & P_{bf} & P_{bm} & P_{bn} \\ 1 & P_{bc} & P_{cc} & P_{cd} & P_{ce} & P_{cf} & P_{cm} & P_{cn} \\ 1 & P_{bd} & P_{cd} & P_{dd} & P_{de} & P_{df} & P_{dm} & P_{dn} \\ 1 & P_{be} & P_{ce} & P_{de} & P_{ee} & P_{ef} & P_{em} & P_{en} \\ 1 & P_{bf} & P_{cf} & P_{df} & P_{ef} & P_{ff} & P_{fm} & P_{fn} \\ 0 & P_{bm} & P_{cm} & P_{dm} & P_{em} & P_{fm} & P_{mm} & P_{mn} \\ 0 & P_{bn} & P_{cn} & P_{dn} & P_{en} & P_{fn} & P_{mn} & P_{nn} \end{vmatrix}}{\begin{vmatrix} P_{aa} & P_{ab} & P_{ac} & P_{ad} & P_{ae} & P_{af} & P_{am} & P_{an} \\ P_{ab} & P_{bb} & P_{bc} & P_{bd} & P_{be} & P_{bf} & P_{bm} & P_{bn} \\ P_{ac} & P_{bc} & P_{cc} & P_{cd} & P_{ce} & P_{cf} & P_{cm} & P_{cn} \\ P_{ad} & P_{bd} & P_{cd} & P_{dd} & P_{de} & P_{df} & P_{dm} & P_{dn} \\ P_{ae} & P_{be} & P_{ce} & P_{de} & P_{ee} & P_{ef} & P_{em} & P_{en} \\ P_{af} & P_{bf} & P_{cf} & P_{df} & P_{ef} & P_{ff} & P_{fm} & P_{fn} \\ P_{am} & P_{bm} & P_{cm} & P_{dm} & P_{em} & P_{fm} & P_{mm} & P_{mn} \\ P_{an} & P_{bn} & P_{cn} & P_{dn} & P_{en} & P_{fn} & P_{mn} & P_{nn} \end{vmatrix}} \text{ microfarads per mile} \quad (23)$$

$$C_b = 0.0389 \times \frac{\begin{vmatrix} P_{aa} & 1 & P_{ac} & P_{ad} & P_{ae} & P_{af} & P_{am} & P_{an} \\ P_{ab} & 1 & P_{bc} & P_{bd} & P_{be} & P_{bf} & P_{bm} & P_{bn} \\ P_{ac} & 1 & P_{cc} & P_{cd} & P_{ce} & P_{cf} & P_{cm} & P_{cn} \\ P_{ad} & 1 & P_{cd} & P_{dd} & P_{de} & P_{df} & P_{dm} & P_{dn} \\ P_{ae} & 1 & P_{ce} & P_{de} & P_{ee} & P_{ef} & P_{em} & P_{en} \\ P_{af} & 1 & P_{cf} & P_{df} & P_{ef} & P_{ff} & P_{fm} & P_{fn} \\ P_{am} & 0 & P_{cm} & P_{dm} & P_{em} & P_{fm} & P_{mm} & P_{mn} \\ P_{an} & 0 & P_{cn} & P_{dn} & P_{en} & P_{fn} & P_{mn} & P_{nn} \end{vmatrix}}{T} \text{ microfarads per mile} \quad (24)$$

$$C_a = 0.0389 \times \frac{\begin{vmatrix} 1 & P_{ab} + P_{ae} & P_{ac} + P_{ab} & P_{am} + P_{an} \\ 1 & P_{bb} + P_{be} & P_{bc} + P_{bf} & P_{bm} + P_{bn} \\ 1 & P_{bc} + P_{ce} & P_{cc} + P_{cf} & P_{cm} + P_{cn} \\ 0 & P_{bm} + P_{em} & P_{cm} + P_{fm} & P_{mm} + P_{mn} \end{vmatrix}}{\begin{vmatrix} P_{aa} + P_{ad} & P_{ab} + P_{ae} & P_{ac} + P_{ab} & P_{am} + P_{an} \\ P_{ab} + P_{bd} & P_{bb} + P_{be} & P_{bc} + P_{bf} & P_{bm} + P_{bn} \\ P_{ac} + P_{cd} & P_{bc} + P_{ce} & P_{cc} + P_{cf} & P_{cm} + P_{cn} \\ P_{am} + P_{dm} & P_{bm} + P_{em} & P_{cm} + P_{fm} & P_{mm} + P_{mn} \end{vmatrix}} \text{ microfarads per mile} \quad (25)$$

The eighth-order determinants are rather difficult to solve. If the two circuits and ground wires are unsymmetrically placed on the towers, there can be no great simplification, and the eighth-order determinants will have to be solved laboriously by the method of minors to reduce to lower order determinants.

If the two transmission circuits are symmetrically placed on the tower line so that conductors A and D, B and E, C and F have the same capacitances, and ground wire M has the same position with respect to circuit ABC as N has with circuit DEF, then a considerable simplification may be accomplished. Equation 23 may then be reduced (25).

Equations similar to (25) may be written for C_b or C_e, and C_c or C_f. This is accomplished by successive replacement of columns in the numerator by the 1-1-1-0 column. A fourth-order determinant is, of course, easily reduced to three third-order determinants by the method of minors, and these in turn are readily solved.

References

1. Arcing Ground Suppression as Basis for Safe Operation of Super Power Systems, E.

Troeger. *AEG Progress* (*Allgemeine Elektricitäts Gesellschaft*), volume 14, December 1928.

2. The Petersen Coil, W. W. Lewis. *General Electric Review*, volume 38, April 1935.

3. The Application of the Petersen Coil, E. M. Hunter. *General Electric Review*, volume 39, December 1936.

4. Electric and Magnetic Fields (a book), S. S. Attwood. John Wiley & Sons, Inc., 1932.

5. Applications of the Method of Symmetrical Components (a book), W. V. Lyon. McGraw-Hill Book Company, Inc., 1937.

6. Symmetrical Components (a book), C. F. Wagner and R. D. Evans. McGraw-Hill Book Company, Inc., 1933.

Discussion

F. Von Voigtlander (The Commonwealth and Southern Corporation, Jackson, Mich.): Doctor Lyon's analysis and computation of the electrostatic unbalance of a transmission line nicely illustrate the application of the theory of electrostatics to the practical solution of system capacitance unbalance problems.

It is interesting to note, however, that for single-circuit lines, the solution of the unbalanced voltages can be found very simply and directly for any common configuration by reference to charts 3, 22, and 23 of Engineering Report No. 16 of the Joint Subcommittee of Development and Research of the National Electric Light Association and the Bell Telephone System.

Using the example cited in the paper, from chart 3 of Report No. 16, we find that the highest voltage listed for five-foot vertical spacing is 22 kv. Entering chart 23 with 22 kv and lowest conductor 30 feet from the ground, we find the residual voltage to be 1.8 kv. Multiplying by the ratio of the actual line voltage (66 kv) to the voltage corresponding to the given spacing (22 kv), we find the characteristic residual voltage for the 66-kv line to be 5.4 kv. The zero-sequence voltage is one-third of the residual, so we have 1.8 kv for the neutral displacement which agrees exactly with Mr. Lyon's results for the totally nontransposed line. The effect of transpositions can readily be taken into account by multiplying this unbalanced voltage by the ratio of the equivalent nontransposed length to the total length of the system.

For twin circuits and circuits with ground wires, the results from these charts would have to be modified, but for single circuits without ground wires, they are well within the accuracy required for this type of work.

J. A. M. Lyon: The interesting discussion of F. Von Voigtlander tells of an easy method to obtain the residual voltage of a transmission line by means of published charts to which he has made complete reference. There is no denying that the use of such charts is extremely expeditious in obtaining the residual voltage for a simple transmission line composed of a single circuit without a ground wire.

It should be emphasized again that the author chose for the illustration of the method of his paper, the simplest case which occurred on the transmission system involved. It should also be pointed out again that a large portion of the total line mileage is equipped with double-circuit lines; some of these double-circuit lines as well as some of the single-circuit lines have ground wires. The author indicated in his paper a general method which is applicable to all these double- and single-circuit lines with and without ground wires.

Mr. Von Voigtlander grants that his method would not be satisfactory in these more complicated cases, at least not without numerous modifications and extensions of the charts. Such changes in his method would destroy the original simplicity and would thus defeat its purpose.

The Pumping System of the Colorado River Aqueduct

By J. M. GAYLORD
FELLOW AIEE

Synopsis: This paper describes the power features of the aqueduct being built to supplement the water supply of Southern California. Three hundred thousand kilowatts of power ultimately will be transmitted from Boulder Dam to operate 45 synchronous motors driving centrifugal pumps. High efficiency, long life, and simplicity of design are given precedence over close voltage regulation and the elimination of momentary interruptions.

THE Colorado River Aqueduct, which will double the present water supply of Southern California, is in its sixth year of construction and the initial development, originally estimated to cost $220,000,000, is approximately 85 per cent completed. This giant water-supply project is being built by The Metropolitan Water District of Southern California, a public corporation composed at this time (August, 1938) of the cities of Anaheim, Beverly Hills, Burbank, Compton, Fullerton, Glendale, Long Beach, Los Angeles, Pasadena, San Marino, Santa Ana, Santa Monica, and Torrance, a total of 13. The District was organized in 1928; bonds were voted in 1931; in September 1932, the Reconstruction Finance Corporation agreed to buy the first bonds; and construction was started in December of the same year. It is expected that water will be delivered through the aqueduct in 1939.

The project is closely linked to Boulder Dam since the 1,100,000 acre-feet of water appropriated by the District out of the flow of the river will be stored by the Government in Lake Mead and 36 per cent of the firm energy developed at Boulder will be used for the operation of pumping plants on the aqueduct. The power and pumping system, comprising five pumping plants and a 230-kv transmission system, will ultimately demand 300,000 kw of power and use $2^1/_4$ billion kilowatt-hours per year, making the project of special interest to the electrical and mechanical engineer.

Paper number 38-116, recommended by the AIEE committees on power transmission and distribution, general power applications, and electrical machinery, and presented at the AIEE Pacific Coast convention, Portland, Ore., August 9–12, 1938. Manuscript submitted April 19, 1938; made available for preprinting July 19, 1938.

J. M. Gaylord is chief electrical engineer for The Metropolitan Water District of Southern California, Los Angeles.

1. For all numbered references, see list at end of paper.

The Aqueduct

The aqueduct has its intake on the Colorado River just above the confluence of the Bill Williams River 150 miles below Boulder Dam. The Parker Dam, just below the mouth of the Bill Williams, is now being completed by the United States Bureau of Reclamation using funds furnished by the District, and will raise the water 72 feet above river level creating a reservoir of 717,000 acre-feet capacity from which the aqueduct will draw its supply. From its intake at Parker reservoir the main aqueduct extends 241.7 miles to the terminal reservoir at Cajalco. This distance is covered by 92.1 miles of tunnel, 54.5 miles of cut and cover conduit, 62.8 miles of open-lined canals, 28.7 miles of inverted siphons, 1.2 miles of pump-delivery lines, 1.1 miles of open ditch, and 1.3 miles of passage through reservoirs.

From the Cajalco reservoir, distribution conduits will deliver water to the member cities of the District. Five pumping stations lift the water from Parker reservoir at elevation 450 feet above sea level to 1,807 feet, the highest point on the aqueduct, from which point flow is by gravity to the terminal reservoir at elevation 1,405. The problem from the standpoint of the electrical and mechani-

cal engineer was to design and build five pumping plants capable of raising 1,500 second-feet of water through a total net lift of 1,617 feet by means of power obtained principally from Boulder Dam. Figure 1 is a general map of the project showing the location of the transmission lines, pumping plants, and related features of the project.

The Intake plant, figure 10, draws its water directly from the Parker reservoir, lifts it 291 feet, and delivers it through the Colorado River tunnel to Gene Wash reservoir. The Gene pumping plant, figure 11, lifts the water 303 feet additional and delivers it through two tunnels to the Copper Basin reservoir. Since both the Colorado River and Copper Basin tunnels operate as pressure conduits, surge tanks are provided at the tops of each lift. The outflow from Copper Basin is regulated by gates operated by supervisory control from Gene pumping plant. From Copper Basin the water flows by gravity 60 miles to the Iron Mountain pumping plant, figure 12, where the third lift, 144 feet, is made. At this plant no natural storage reservoir is available but a regulating forebay reservoir of 100 acre-feet capacity has been

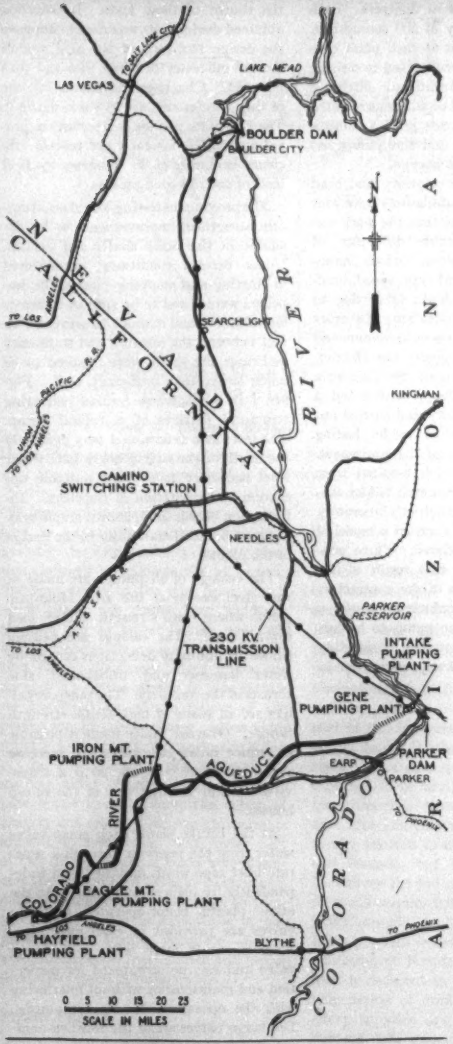


Figure 1. Map of power system for Colorado River Aqueduct and profile of section that includes pumping plant

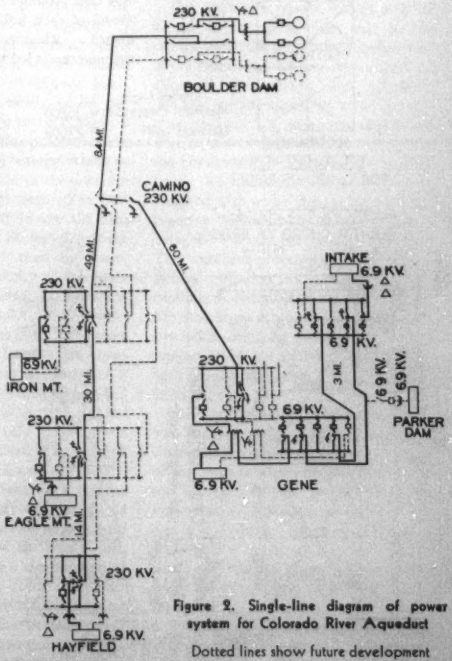


Figure 2. Single-line diagram of power system for Colorado River Aqueduct

Dotted lines show future development

constructed. Normally water is pumped direct from the open canal and in case of power failure it overflows into the reservoir. Two of the pumps in the plant have auxiliary inlets from the reservoir permitting water accumulated during a power outage to be pumped out later. The forebay reservoir will hold the full aqueduct flow for 45 minutes and a siphon spillway provides a means of wasting water onto the desert during a prolonged outage. The next pumping plant in the series is Eagle Mountain, figure 13, with a lift of 438 feet, located 40 miles from the top of the Iron Mountain lift. At this plant also, a 100-acre-foot regulating forebay reservoir has been provided. Sixteen miles farther along the aqueduct is located the Hayfield reservoir, capacity 83,000 acre-feet and the Hayfield pump lift of 441 feet, figure 14. At this plant independent intakes are provided from the canal and from the reservoir, so that any pump can draw water from either source.

Hydraulic Equipment

The pumps are all of the single-stage single-suction vertical-shaft volute type without guide vanes or diffusers. Each pump has a capacity of 200 second-feet. The first installation at each plant consists of three pumps connected to a single discharge pipe. Additional discharge pipes and pumps will be added as required to meet water demands until a total of three discharge lines and nine pumps has been installed in each station.

Few pumps of the capacity and head required for these installations have ever been built, and at the time the work was undertaken considerable difference of opinion existed between various manufacturers as to the best type, speed, number of stages, and depth of setting to insure satisfactory operation. In order to resolve these differences in opinion and to improve pump efficiency the District, with the co-operation of the California Institute of Technology, constructed a pump testing laboratory and carried out a two-year program of model testing prior to the purchase of the equipment. The specifications which resulted from these tests required that each bidder submit for testing in the District's laboratory prior to the award of contract a model of one of the pumps offered. Three contracts were awarded as a result of this competition and each of the contractors was then required to submit for testing a model of each full-size pump to be furnished. Rivalry between competing manufacturers led to keen competition in the course of these tests. Information obtained during tests was used to improve the design and each of the final models showed efficiency between 91.5 and 92.5 per cent. Characteristic curves for one of the Gene models are given in figure 9. The contracts provide for bonuses aggregating $55,000 for each per cent in efficiency in excess of 88 as shown by field tests of the full-sized pumps.

The program of testing also showed certain structural improvements to be desirable in the pump shafts and casings. Under certain conditions, encountered in starting and stopping pumps, the impellers were found to be subject to heavy lateral forces and in order to prevent contact between the rotating and stationary seal rings the shafts were required to be much larger than ordinarily used. Figure 7 is a transverse section indicating structural features of a typical pump. The tests also determined very definitely the depth of the setting below inlet water level necessary to prevent unstable operation and cavitation of impellers. Information of this kind, shown graphically in figure 8, aided materially in the design of the plants.

The casings of all pumps are made of cast steel except at the Iron Mountain plant where high-strength nickel cast iron is used. The casings are heavily ribbed to minimize deflections caused by water hammer and unbalanced side thrusts of the impellers. The pump impellers are all made of high-tensile-strength bronze. Oversize shafts made it possible to reduce radial clearances and increase pump efficiency. Figure 20 is a transverse section through one of the pump houses.

At the Intake plant, each pump takes water from the reservoir through a separate inlet pipe which may be closed independently by plain sliding gates. At the other plants motor-operated butterfly valves are provided in each inlet pipe. Each pump is fitted with a discharge valve and can be unwatered for inspection and maintenance without interfering with the operation of adjacent pumps. Discharge valves are of the rotating-conical-plug type operated by oil cylinders. This valve when fully opened has a circular water passage tapered to correspond to the increasing diameter of the pump-discharge nozzle. In operating the valve in either direction the operating mechanism first raises the plug slightly to unseat it, rotates it to the desired position, then lowers the plug, and reseats it. The oil pressure system is similar to that ordinarily used to operate the Servomotors of hydraulic turbine governors.

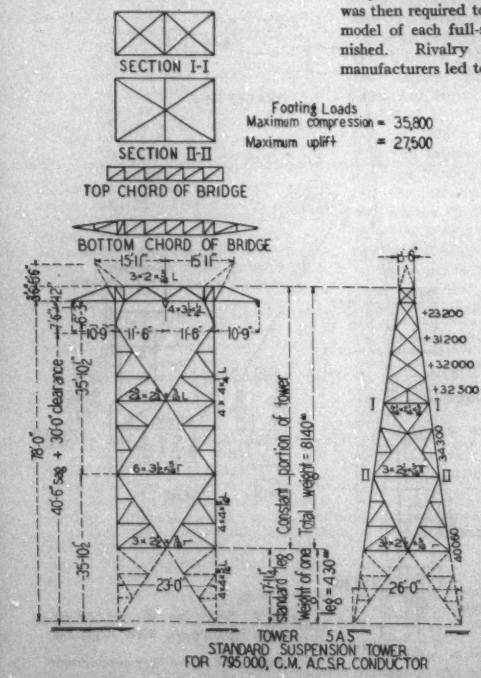


Figure 3. Standard suspension tower, type 5AS

For 795,000 circular mils, aluminum steel reinforced conductor

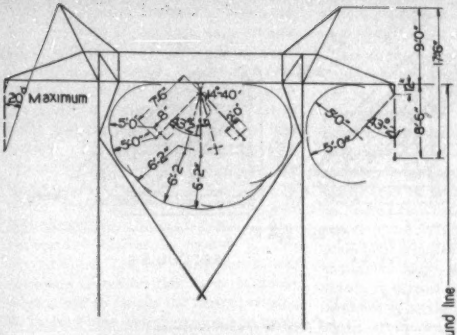


Figure 4. Clearance diagram

For standard suspension tower, type 5AS for 795,000 circular mils aluminum steel reinforced conductor

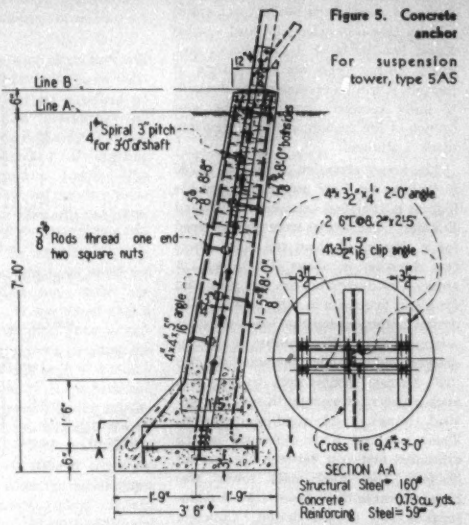


Figure 5. Concrete anchor

For suspension tower, type 5AS

Oil for operation is kept under air pressure in accumulator tanks in sufficient quantity for two complete valve operations without recourse to the oil pumps. Pressure surges in the pipe lines, which occur when the pumps are suddenly stopped due to power failure, are held within permissible values by the operation of the discharge valves under the control of a device similar to a hydraulic turbine governor. Upon failure of the power supply the discharge valves close rapidly to the point of definite throttling of the flow. During this interval the moving water column in the discharge pipe comes to rest due to the action of gravity and return flow from the pump is allowed to commence. The latter part of the closing stroke is made very slowly and the reverse flow brought to zero with definite limitation as to increase in pressure. The device is susceptible of adjustment to insure complete closure without excessive pressure rise and before dangerous speed reversal occurs.

Power Supply

The Metropolitan Water District was one of the three principal underwriters of Boulder Dam. The Boulder Canyon Act authorized the Secretary of the Interior to begin construction of the dam only after he had obtained power contracts guaranteeing the return of the Government's investment within a term of fifty years. Contracts with The Metropolitan Water District, the City of Los Angeles (Bureau of Power and Light), and the Southern California Edison Company, meeting the above requirements were consummated in the spring of 1930. Under its contract the District was allotted and agreed to pay for 1,526,000,000 kilowatt-hours per year (subject to a small annual diminution and the three-year load-building allowance), which is 36 per cent of the firm energy to be developed at the dam. It was also given the first right to use secondary energy which is expected to be available in considerable quantities from time to time. The District also has the right to use the firm energy allotted to the States of Arizona and Nevada, but not used by them. To deliver the full capacity of the aqueduct will require 2,250,000,000 kilowatt-hours annually, or 724,000,000 kilowatt-hours per year in excess of its firm power allotment at Boulder Dam. The aqueduct is designed to provide water for a long period of development of the territory supplied and the growth of the demand will undoubtedly extend over many years. The District's present firm energy supply will undoubtedly be in excess of its requirements for a number of years, but when this firm supply is exceeded the deficiency can be made up by taking over some of the States' firm power, if unused, or by a combination of secondary and standby power to be purchased from other allottees of Boulder Dam power. In addition to these power resources the District owns one-half of a 100,000-kw power site at Parker Dam.

Transmission Line

The District's power system was designed as an independent unit to efficiently meet the particular requirements of the situation. Sturdy mechanical and electrical construction, high efficiency, and low maintenance were given primary consideration. Of secondary importance were regulation of speed and voltage and the elimination of momentary interruptions. The aqueduct, as a whole, was designed with water storage and carrying capacity sufficient to allow for service outages of seven per cent of the time. This condition practically eliminates any serious objection to momentary interruptions of electrical power service. For this reason no attempt was made to design what could be considered an interruption-proof transmission line. Overhead ground wires and counterpoise were omitted.

The transmission voltage of 230,000 was selected as the result of extensive studies to determine the type and voltage of the system which would give lowest cost during a 50-year period considering maintenance, depreciation, interest, and cost of lost power. A similar study of the transmission problem between Intake, Gene, and Parker power plant resulted in the adoption of 69 kv for this part of the system.

The initial and final development of the system are shown in figure 2. The first installation is a single circuit throughout.

A second circuit from Boulder to Camino will be necessary when the load reaches about two-thirds of its maximum and, unless energy costs are lower than at present, it will be economically advisable to build a second circuit on the west branch of the system when full development is attained.

The lowest elevation of the line is 750 feet above sea level near Gene, and the highest is 3,650 feet between Camino and Boulder. The towers were strengthened for a distance of about ten miles where the elevation is above 3,200 feet. A reduced conductor tension was also used for about five miles in this section. The design for the transmission line towers was selected from a large number of studies, designs, and estimates, including wooden "H" frames, flexible-steel frames with anchor towers at each tenth span, guyed-steel frames, and rigid-steel towers. There was but little difference in the estimated first cost between the various designs. The rigid steel tower was chosen because of its lower cost of maintenance and rugged design. Concrete footings, figure 5, were used throughout the line, except in a few places where towers were set on native rock and excepting the Danby Dry Lake crossing where creosoted pile foundations, figure 6, were found to be necessary to protect the metal and concrete from the corrosive action of the concentrated alkali of the soil. Five different towers are used and the designs provide for legs shorter or longer than standard to meet side-hill conditions. One tower of each type was tested at 50 per cent overload and one standard suspension tower was tested to destruction. In the latter test, failure occurred in the overhanging arm of the bridge at 90 per cent overload.

Two complete lines were located and designed, one for copper and one for steel-reinforced aluminum conductor and alternative bids for all work and materials were taken at the same time. Alternative bids also were permitted on towers to be designed by the bidder to determine the savings, if any, due to the rotated base and waisted designs. The aluminum line proved to be approximately ten per cent cheaper than the copper line and the District design of conventional tower, figure 3, was materially lower in price than any of the others. The line includes 227 miles of steel-reinforced aluminum circuit and ten miles using hollow copper conductor of the twisted I-beam type.

Simple, strong fittings of standard design are used. Suspension clamps were selected after tests at the factory to determine the seat curvature best adapted to minimize vibration stresses. Strain clamps are of the compression type. The aluminum conductor and its steel core are gripped separately, but the clamps for copper compress the entire cable. Vibration dampers of the Stockbridge type are used on both aluminum and copper. Armor rods are also used on the aluminum conductors as an additional safeguard against vibration damage and to protect the conductor against arcs. Arcing horns are not used on insulator assemblies but sufficient clearance has been allowed to permit their installation at a later date if desired. It is a well-established fact that vibration troubles increase with conductor tension and in the interest of long life and low-maintenance cost a conservative value was adopted, namely, a tension of 30 per cent of the ultimate strength at 25 degrees Fahrenheit with a wind load of eight pounds per square foot. The normal level span was fixed at 1,370 feet, or less than the economic span, in the belief that the resulting lower tower height would reduce the lightning hazard.

In establishing clearances between the transmission-line conductors and steel, the dimensions were adjusted to maintain full flashover value of the insulators with the conductor subjected to a wind velocity of about 32 miles per hour. A higher wind velocity will reduce the clearances, but even with an actual wind velocity of 56 miles per hour the clearances will be sufficient to prevent flashovers due to switching surges ordinarily to be expected. The transmission-line profile, of course, is not level and, in order to allow for all possible conditions, clearances were determined for a three-degree angle in the line. The conductor-to-steel clearances are 60 inches with a three-degree angle and a wind pressure of eight pounds per square foot and 74 inches with a 3-degree angle and a wind pressure of $2\frac{1}{2}$ pounds per square foot. Figure 4 is the clearance diagram for the standard suspension tower.

The towers carry two ground wires for approximately one mile from each station. Mid-span clearance between conductors and ground wires is 30 feet with aluminum conductors and 20 feet with copper conductors.

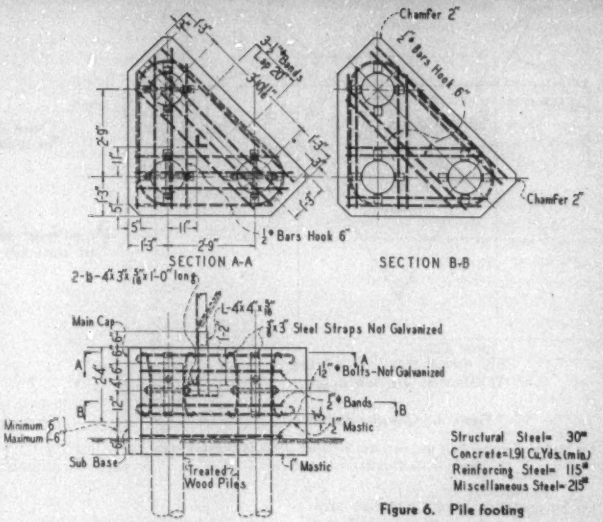


Figure 6. Pile footing

For special suspension tower, type SAH

Motors

The completed installation will include 45 6.9-kv synchronous motors ranging in size from 4,300 to 12,500 horsepower. Each motor is equipped with direct-connected main and pilot exciters, and is designed for full-voltage across-the-line starting. All motors are totally enclosed for recirculation of air, are water cooled, and provided with carbon-dioxide fire protection. In the preliminary studies of system design it was apparent that normal character-

istics of generators and motors would not give the required stability of operation and a radical reduction in system reactance was necessary. Within practical limits the reactance values of the generators could be reduced at less cost than could the corresponding values of the motors. There was, however, an economic limit to such reduction and, having reached this limit, the improvement of motor characteristics offered the next best possibility. Normal value of synchronous reactance in motors of this size is about 110 per cent, but it was necessary to reduce this value to about 50 per cent to obtain the desired results. In making this determination the problem was set up on an a-c calculating board and solution obtained for the steady-state operating limit. The effect of saturation of the iron in the motors was taken into consideration and their reactance was expressed in terms of equivalent reactance which corresponds to that under actual operating conditions. After the motor characteristics for steady-state operation had been determined, further study was made on a calculating board of the transient conditions occurring when each motor is started. As a result of these studies an equivalent reactance value of 34 per cent at 105 per cent rated output and 95 per cent voltage was specified. Calculations indicated that this figure will give a power margin of about 25 per cent for the present transmission system with four motors operating at each plant.

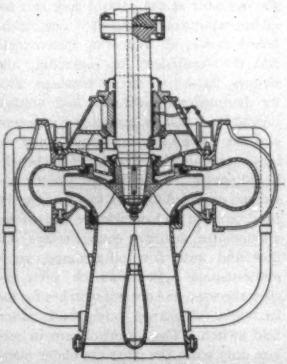


Figure 7. Transverse section through pump, capacity 200 cubic feet a second against 310-foot head, 400 rpm

Extra heavy shaft to resist unbalanced radial forces when starting

Main bearing is self-aligning, casing heavily reinforced with cast steel ribs

Across-the-line starting of motors will produce heavy momentary drops in voltage but, since this system supplies no power customers and practically no lighting load, voltage drops are not objectionable. This method of starting greatly simplifies station design. The initial rush of current at starting must be limited to a value that will not allow the terminal voltage to drop below the minimum required for starting the first motor or below the value required for stable operation when more than one motor is in service. It was found that a single amortisseur winding gave a sufficiently low inrush as well as adequate starting torque and this type of winding was adopted because of its substantial construction. The specifications require the motors to produce sufficient "break away" torque to overcome starting friction and the most difficult condition is that which occurs when the initial motor is started in the pumping plant farthest from the generators. As each additional motor is placed in operation, those already in service, with the assistance of their voltage regulators, help to maintain normal voltage giving greatly improved starting conditions. Starting the last motor, however, is the most critical operation as the system is then closer to its power limit. When the 20th motor is started on the single-line system, there will be a margin of stability of about 25 per cent if all regulators are out of service and 35 per cent with the regulators in service. Each motor is required to develop at least 14 per cent of rated torque in starting with normal voltage maintained at Camino. Each motor must bring the pump to synchronous speed with water in the casing, discharge valve closed, and the voltage back of the transient reactance held normal at the generators. At the speed for field application the torque must be sufficient to drive the pump under the above hydraulic conditions with the field short-circuited through a starting resistor or with the field short-circuited upon itself and also with field applied at the most unfavorable angle for synchronizing. These requirements insure that the motors may be easily synchronized regardless of the angle at which the field is applied.

Receiving Stations

The main transmission line extends to all of the pumping plants except Intake which is supplied with power at 69 kv from Gene. At each plant one bank of transformers has been installed and this constitutes one-half of the ultimate installation. Transformers are wye-connected on the high side with neutrals solidly grounded and delta-connected on the low tension sides. All transformers are water cooled and provided with nitrogen-seal equipment. The 230-kv receiving stations are provided with a main bus and a transfer bus as indicated in figure 15. Because of lack of ground space a high steel structure is used and in the case of the disconnecting switches between the incoming circuits and the oil circuit breaker, the blades of the disconnecting switches are placed in a vertical position. All other high-voltage disconnects are of the horizontal-break type supported on tripods made up of standard high-strength line insulators. The disconnecting switches are motor-operated and controlled from the main bench-

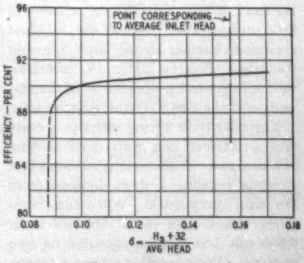


Figure 8. Typical cavitation characteristic

H_s = Static inlet head on center line of impeller. Average head = average total pumping head

Note the abrupt drop in efficiency as the inlet head is reduced

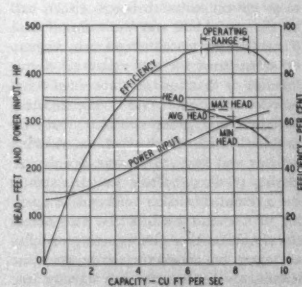


Figure 9. Complete pump characteristic

Laboratory test of contractor's model for Gene pumping plant. Model ratio 1 to 5.53, tested at 2,133.5 rpm

Note efficiency of over 90 per cent throughout operating range

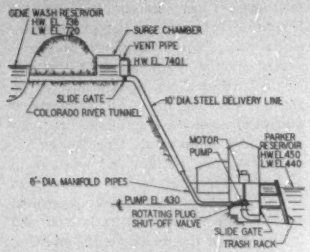


Figure 10. Intake pumping plant

Schematic profile

Pump data: Average head 294 feet—capacity 200 cubic feet a second each—speed 400 rpm—motors 9,000 horsepower each

Number of pumps: 3—initial installation
9—ultimate installation

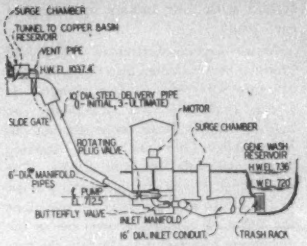


Figure 11. Gene pumping plant

Schematic profile

Pump data: Average head 310 feet—capacity 200 cubic feet a second each—speed 400 rpm—motors 9,000 horsepower each

Number of pumps: 3—initial installation
9—ultimate installation

board. The high-voltage oil circuit breakers, having a rupturing capacity of 2½ million kva, are of the oil-blast explosion-chamber type and solenoid operated. Figures 16 to 19, inclusive, show the general arrangement of the stations and the design of the switch racks.

The 6,900-volt wiring includes a main and a transfer bus with disconnecting switches and circuit breakers located in a separate building a short distance from the main pump house. When two transformer banks are in service the main 6,900-volt bus will be operated as two sections. Disconnecting switches permit sectionalizing at any one of six places between positions 3 and 7, allowing approximately equal loading of each part of the bus and each bank of transformers. A bus-tie position is provided which by means of disconnecting switches may be connected between either half of the main bus and the transfer bus. Thus the bus-tie oil circuit breaker may be substituted for any motor oil circuit breaker or that for the station light and power position. All disconnecting switches are group-operated and are provided with mechanical interlocking devices and keys to prevent opening or closing of disconnecting switches should the associated breaker be closed, or opening of a circuit breaker cell door unless the circuit breaker disconnecting switches are open, or, connecting more than one circuit to the transfer bus at any one time. The 6,900-volt buses are constructed from one-quarter-inch by four-inch copper bars except at Eagle and Hayfield plants where 5-inch copper channels are used. Special heavy-duty expansion-type bus clamps are provided. All buses are bolted together with ⅝-inch Everdur bolts and all contacts are silver plated. The 6.9-kv oil circuit breakers have an interrupting capacity of 500,000 kva and are rated at 600 and 1,200 amperes. These breakers are of the oil-blast type and are solenoid operated. The oil circuit breaker isolating switches are six-pole, group-operated, and mechanically interlocked with the circuit breakers. All others are three-pole, group-operated switches. All disconnecting switches are enclosed in steel compartments and a set of key interlocks is provided to prevent improper operation.

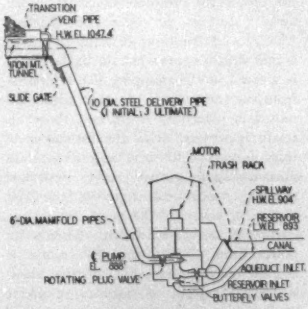


Figure 12. Iron Mountain pumping plant

Schematic profile

Pump data: Average head, 146 feet—capacity 200 cubic feet a second each—speed 300 rpm—motors 4,300 horsepower each

Number of pumps: 3—initial installation
9—ultimate installation

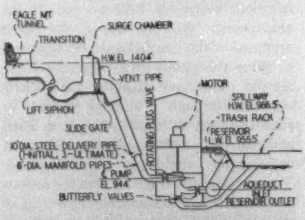


Figure 13. Eagle Mountain pumping plant

Schematic profile

Pump data: Average head 440 feet—capacity 200 cubic feet a second each—speed 450 rpm—motors 12,500 horsepower each

Number of pumps: 3—initial installation
9—ultimate installation

Station Control

The control rooms are so arranged that the operator at the control desk can see all important control panels. The benchboard carries all indicating instruments and the equipment for controlling the motors, 230-kv oil circuit breakers, 230-kv disconnecting switches, and voltage regulators. Station metering equipment and the 230-kv line and transformer relays are mounted on the rear of the benchboard panels. Individual panels or cubicles are provided for each motor. On the front panel of each cubicle are located the annunciator, auxiliary control relays, oil-flow and water-flow pilot lamps, automatic-manual selector switch, pilot exciter rheostat, and control switches for inlet valve, discharge valve, and motor field switch. These controls are in service only when the units are under manual control and are inoperative during automatic operation. The rear panel of

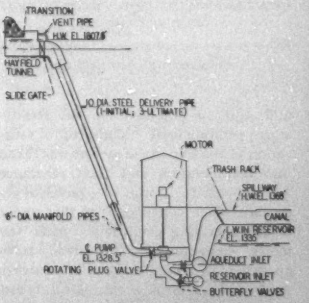


Figure 14. Hayfield pumping plant

Schematic profile

Pump data: Average head 444 feet—capacity 200 cubic feet a second each—speed 450 rpm—motors 12,500 horsepower each

Number of pumps: 3—initial installation
9—ultimate installation

Figure 15. Single-line wiring diagram—Iron Mountain pumping plant

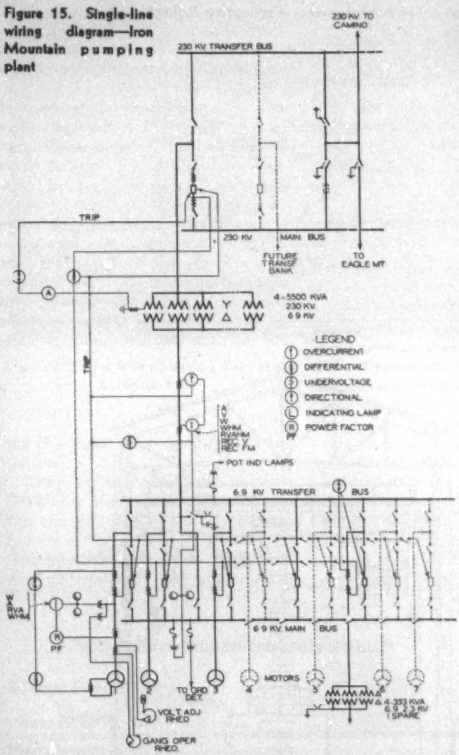
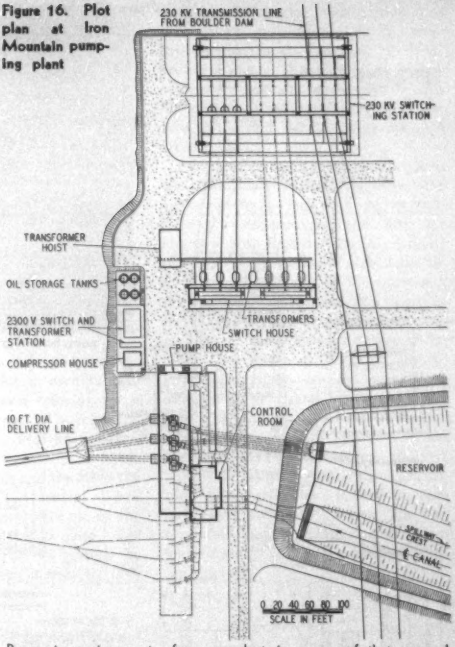


Figure 16. Plot plan at Iron Mountain pumping plant



Reservoir receives water from aqueduct in excess of that pumped

Substructure of pump house completed for ultimate of nine pumps

Outdoor hoist for transformer repair

Spare single-phase transformer can be connected in either of two banks without moving

the cubicle carries the overload and differential relays, voltage regulator with its cut-out switch, and the watthour meter. Other panels carrying d-c controls, temperature and water-line indicators, and telephone equipment are located in frames set flush with the walls of the control room. Access to the rear of these panels is obtained from adjacent rooms. Incoming control cables terminate on racks in the control room basement which are provided with terminal blocks for cable conductors and panel wiring.

Under automatic control, before a pumping unit can be started, it is required that the water for cooling and oil for lubrication be functioning properly, that the inlet valve be open, and the discharge valve closed. The pump is then started with the motor field short-circuited through a resistance. As the motor approaches synchronous speed, a synchronizing relay, described later, causes the field switch to close, bringing the motor into synchronism. The voltage regulator is then automatically brought into service and the pump discharge valve opened, establishing flow in the discharge pipe and fully loading the motor. In the normal stopping of a pump the discharge valve is first closed and then the motor oil circuit breaker opened. In case of an emergency shut-down, the motor oil circuit breaker opens immediately and the discharge valve closes under control of the hydraulic surge suppressor previously described.

In the motor-starting scheme, provision is made for automatically applying the motor field when the field flux linkages are a maximum. This occurs twice every slip cycle and the rotor is then in a favorable position for being brought into synchronism. At the instant of maximum field flux linkages the induced field current is zero and the armature current is a minimum. Near synchronous speed the armature current pulsates at a rate proportional to the slip. The field-application relay which is of the wattmeter type closes its contacts at a minimum instantaneous value of the pulsating current. As the pulsations become less frequent, the relay contacts remain closed for a longer period. When the closing period attains a predetermined duration, a series of timing relays operate to close the field breaker at multiples of a half slip cycle later corresponding to a time for maximum field flux linkages. The motor speed at which the field-application relay operates is independent of the voltage. This is accomplished by equipping the synchronous relay with a restraining coil having a torque proportional to the square of the voltage and an operating coil proportional to the motor power input which is proportional to the square of the voltage. After synchronizing the motor the circuit of the potential coil of the wattmeter-type relay is altered so that it becomes a power-factor relay which trips the motor breaker on low power factors resulting from out-of-step conditions.

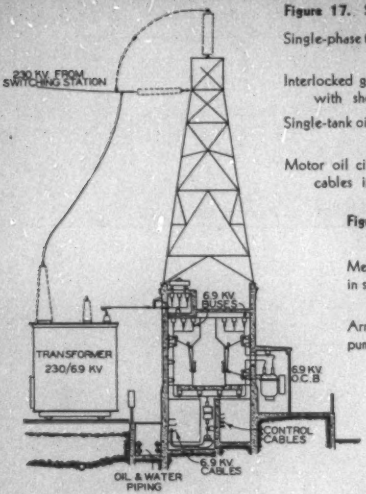


Figure 17. Section through 6.9-kv switch houses

Single-phase transformers with short bar connections to buses

Interlocked gang operated disconnecting switches with sheet-metal barriers between circuits

Single-tank oil circuit breakers in cells that open to out-of-doors

Motor oil circuit breakers at switch house with cables in tunnel direct to motor terminals

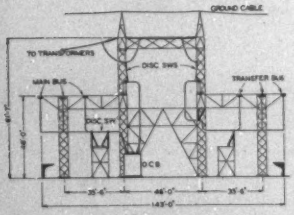


Figure 18. Transformer section of 230-kv switching station

Steel structure is latticed column and girder construction

Busses are of copper line conductor supported by strain insulators

Bus taps are copper tubing

Remote controlled motor-operated disconnecting switches are either horizontal or vertical break

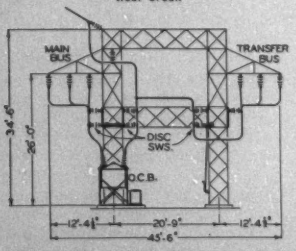


Figure 19. Section of 69-kv switching station

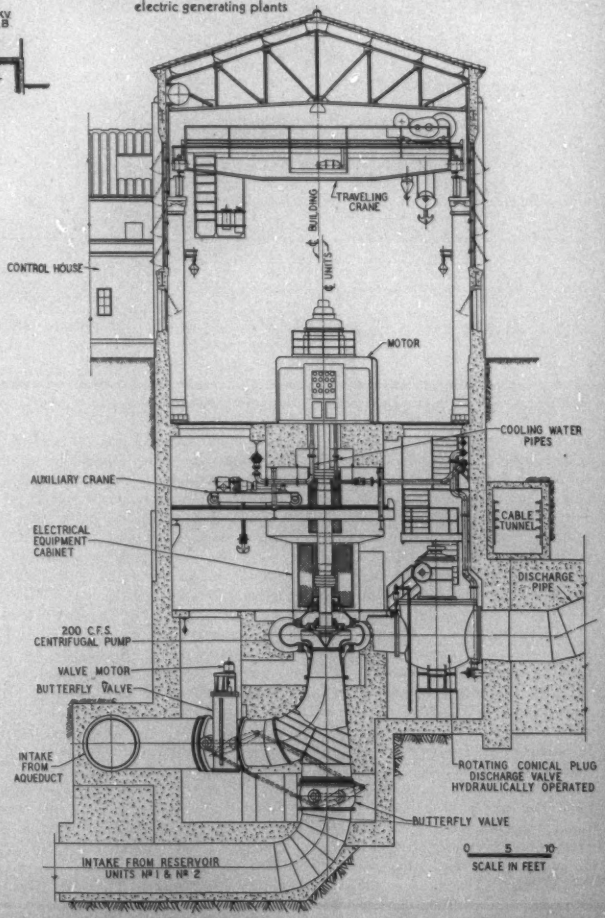
Steel structure is latticed column and girder construction

Disconnecting switches over oil circuit breakers are six-pole, one mechanism per circuit

Figure 20. Iron Mountain pumping plant—section through pump house

Mechanically connected butterfly valves in suction permit water to be taken from either the aqueduct or reservoir

Arrangement of pump, motor, cranes, and pump house very similar to that in hydroelectric generating plants



Protective Relays

Relays for a power system such as this are principally for the protection of lines and apparatus rather than the sectionalizing of the equipment for continuity of service. The simpler types of relays are used and each line and each piece of major apparatus is provided with relays in order to facilitate the location of faults. Phase protection of the 230-kv system is accomplished by directional-type relays at the pumping plants and impedance-type relays at Boulder. The latter are used because of the small difference between currents at Boulder resulting from a short circuit at the extremities of the line and those that flow during the start-

Figure 21. The Intake pumping plant at the Colorado River

ing of a motor when the system is near full load.

Relays for line-to-ground faults on the 230-kv line are of the overcurrent induction type and operate from current transformers in the transformer neutrals. At Gene pumping plant, because of the three-winding transformer bank with both 230-kv and 69-kv neutrals grounded, a directional overcurrent relay is used to prevent the 230-kv breaker tripping for a fault in the 69-kv system. The relay has two current elements, one of which measures the sum of the currents in both the 230- and 69-kv neutrals and the other the current in only the 230-kv neutral. When the currents in the two coils are in the same direction, the contacts close. For ground faults on the 230-kv system the only current in the relay is from the 230-kv fault and the relay contacts are set to close under this condition. For faults on the 69-kv system the current in the 69-kv neutral is greater than that in the 230-kv neutral and opposite in direction. Thus the relative direction of current in the coils is reversed and the relay contacts are held open.

For phase protection of the 69-kv lines duo-directional induction-type relays with instantaneous overcurrent relays and cross-connected current transformers are placed at both Gene and Intake pumping plants. For protection of each single 69-kv line and to back up the duo-directional relays, overcurrent induction-type relays are placed at Gene and directional-overcurrent induction-type relays at Intake. The relays at Gene for line-to-ground protection are the overcurrent induction type and at Intake the directional overcurrent type with residual voltage obtained from capacitors on the breakers for the directional element.

Differential protection with induction-type differential relays is used on each motor and each transformer. The motors also have overload relays with a long-time setting to prevent tripping during starting.

Appendix. Equipment Characteristics

Boulder Power Plant

Generators

Number installed initially	2
Number to be installed ultimately	4
Kilovolt-amperes each at unity power factor	82,500
Voltage	16,500
Number of poles	40
Speed, revolutions per minute	180
Short-circuit ratio	2.74
Direct-axis transient reactance, per cent	17.5
Moment of inertia (WR^2) each—not less than	105,000,000
Total weight, pounds, approximate	2,000,000
Outside diameter, feet	40
Type of insulation	Class *B*
Excitation—nominal 250 volts, main and pilot exciter direct connected	
Exciter response	0.50

Power Transformers

Number initially installed	4
Number to be installed ultimately	7
Type	Water cooled outdoor
Rating of each, kilovolt-amperes, single-phase	55,000
Voltage	230,000 Y/16,500 delta
Frequency, cycles per second	60
Impedance, per cent	10.8
Exciting current at normal voltage, per cent	2.4
Full-load efficiency, per cent	99.51
Half-load efficiency, per cent	99.52
Total weight per unit with oil, pounds	243,000
Floor space and height, feet	10½ by 12½ by 30
Quantity of oil per unit, gallons	9,300

Oil Circuit Breakers—High Voltage

Type	Outdoor 3 tank
Voltage class, kilovolts	230
Interrupting capacity, kilovolt-amperes	2,500,000
Normal current rating, amperes	1,200
Speed of opening, cycles	Less than 8
Weight with oil, pounds	204,000
Gallons of oil, per breaker	15,500

Pumping Plants

High-Voltage Oil Circuit Breakers

	Intake and Gene	Gene, Iron Mountain, Eagle, and Hayfield
Type	Outdoor 3 tank	Outdoor 3 tank
Voltage class, kilovolts	69	230
Interrupting capacity, kilovolt-amperes	500,000	2,500,000
Normal current rating, amperes	600	1,200
Speed of opening, cycles	Less than 5	Less than 5
Weight with oil, pounds	13,200	183,600
Floor space and height, feet	11 by 6 by 11	12 by 45½ by 21½
Gallons of oil	600	13,000

Low-Voltage Oil Circuit Breakers

	Intake, Gene, Eagle Mountain, and Hayfield	Iron Mountain Plus Auxiliary Service, All Plants
Type	Indoor cell	Indoor cell
Voltage class	6,900	6,900
Interrupting capacity, kilovolt-amperes	500,000	500,000
Normal current rating, amperes	1,200	600
Speed of opening, cycles	Less than 5	Less than 5
Weight with oil, pounds	3,378	3,374
Gallons of oil	82	82

Motors

Number initially installed	3 at each plant—total 15
Number to be installed ultimately	9 at each plant—total 45
Type each	Totally enclosed synchronous
Voltage	6,900
Excitation	125 volts, main and pilot exciter direct connected
Exciter response	1.0

	Intake and Gene	Iron Mountain	Eagle Mountain and Hayfield
Horsepower rating, each	9,000	4,300	12,500
Speed, revolutions per minute	400	300	450
Number of poles	18	24	16
Short circuit ratio	2.15	2.19	2.26
Direct axis transient reactance, per cent	25.4	21.5	26
Starting inrush of normal current, per cent	586	646	517
Moment of inertia (WR^2) each, pound feet²	397,600	296,000	430,000
Type of insulation	Class *B*	Class *B*	Class *B*
Total weight, pounds each	160,000	97,500	180,000

Transformers

Type, each single phase	Outdoor, water cooled
Frequency, cycles per second	60

	Intake	Gene	Iron Mountain	Eagle Mountain and Hayfield
Number used initially	12	3	3	3 each
Number used ultimately	24	6	6	6 each
Number spare units	..	1	1	1 for both plants
Rating kilovolt-amperes each at 230 kv	..	22,000	5,500	15,000
Ditto, each at 69 kv	2,000	11,000	..	..
Ditto, each at 6,900 volts	2,000	11,000	5,500	15,000
High voltage	69,000 Delta	230,000Y	230,000Y	230,000Y
Intermediate voltage	..	69,000Y	..	..
Low voltage	6,900 Delta	6,900 Delta	6,900 Delta	6,900 Delta
Impedance—				
230 to 6.9 kv (per cent)	..	9.29	9.77	10.00
230 to 69 kv (per cent)	..	11.28	..	..
69 to 6.9 kv (per cent)	9.1	20.53	..	..
Exciting current at normal voltage, per cent	1.26	2.75	3.39	3.50
Full-load efficiency, per cent	99.00	99.39	99.13	99.35
Half-load efficiency, per cent	99.05	99.30	99.06	99.27
Total weight per unit, pounds	40,300	211,000	109,000	155,000
Floor space and height, feet	8 by 8 by 16	10 by 17 by 27	8½ by 12 by 24¼	9¼ by 15½ by 25

Pumps

Characteristics and Principal Dimensions

	Intake	Gene	Iron Mountain	Eagle Mountain	Hayfield
1. Total pumping head including pipe losses in feet—Average	294	310	146	440	444
2. Ditto—Maximum	303	324	156	452	476
3. Ditto—Minimum	272	286	133	427	432
4. Inlet pressure heads in feet when total pumping head is—Average	14	17	15	20	37
5. Ditto—Maximum	9	5	5	10	5
6. Ditto—Minimum	19	23	16	22	37
7. Speed rpm	400	400	300	450	450
8. Specific speed, gallons-per-minute units	1,690	1,624	2,140	1,403	1,395
Impeller dimensions, inches					
9. Outside diameter	76	78	74⅛	81 13/16	81 13/16
10. Inlet diameter	40	40	40⅞	34	34
11. Width at discharge	9.703	8.833	12⅝	7.0	7.0
12. Inside diameter discharge flange	42	42	48	40½	40½
13. Number of vanes	8	8	6	9	9
14. Shaft diameter, inches	22	22	20	24	24

The discharge capacity of each pump at average or rated head is 200 cubic feet per second.

230-Kv Transmission Line

Conductors

Steel Reinforced Aluminum (ACSR)

Circular mils of aluminum	795,000
Strands of aluminum	26
Diameter of aluminum strands, inches	.1749
Strands of steel	7
Diameter of steel strands, inches	.1360
Diameter of conductor, inches	1.108
Weight per foot, pounds	1.093
Ultimate strength, pounds	31,200

Copper

Circular mils total	510,900
I-beam section core, circular mils	44,300
Intermediate layer, 22 wires, diameter, inches	.0966
Outer layer, 28 wires, diameter, inches	.0966
Diameter of conductor, inches	1.004
Weight per foot, pounds	1.61
Ultimate strength, pounds	22,500

Overhead Ground Wire

Number per tower	2
Double-galvanized high-strength strand, 1/4 inch with 7 wires	
Diameter of each wire, inches	.165
Weight per foot, pounds	.517
Breaking strength, pounds	21,000

Conductor Tensions

	Copper	ACSR
Maximum design tension at elevations over 3,200 feet at 0° F., 1/2 inch of ice and a wind pressure of 6 pounds per square foot, pounds	..	14,800
Maximum design tension at elevations under 3,200 feet at 25° F. and a wind pressure of 8 pounds per square foot, pounds	6,700	9,380
Maximum design tension adjacent Gene and Boulder at 25° F. and a wind pressure of 8 pounds per square foot, pounds	..	5,600 adjacent to Boulder 8,100 adjacent to Gene

Ground-Wire Tensions

	Over Copper	Over ACSR
Maximum design tension in 1/4 inch steel ground wire	3,000	6,100

Towers

Type 5AS, Standard Suspension, Aluminum Conductor

Designed for light loading (8 pound wind at 25° F.):
1. Normal level span of 1,370 feet, with an angle in the line of 1° 30'.
2. Maximum span of 1,710 feet with no angle.
3. One broken conductor or one broken ground wire.

Weight of constant portion of tower, with standard legs, pounds	10,216
Weight of steel in concrete footings, per tower, pounds	788
Quantity of concrete in footings, per tower, cubic yards	2.92
Number of towers	736

Type 5AA, Suspension Tower, Aluminum Conductor

Designed for light loading (8 pound wind at 25° F.):
1. Normal level span of 1,370 feet, with an angle in the line of 9°.
2. Maximum span of 1,800 feet with an angle in the line of 9°.
3. Maximum span of 2,600 feet with an angle in the line of 5°10'.
4. One broken conductor or one broken ground wire.

Weight of constant portion of tower with standard legs, pounds	11,841
Weight of steel in concrete footings, per tower, pounds	1,008
Quantity of concrete in footings, per tower, cubic yards	3.80
Number of towers	87

Type 5AR, Suspension Type for Aluminum Conductors—for use at railroad crossings

Designed for heavy loading (6 pound wind on wires covered with 1/2 inch of ice):
1. Normal level span of 1,376 feet.
2. Two broken conductors or one broken ground wire.

Weight of constant portion of tower with standard legs, pounds	13,625
Weight of steel in concrete footings, per tower, pounds	1,528
Quantity of concrete in footings, per tower, cubic yard	4.92
Number of towers	12

Type 5AD, Anchor Tower

Designed for light loading (8 pound wind at 25° F.):
1. Span of 1,500 feet, 39° angle in line and no wires broken.
2. Span of 1,700 feet, 39° angle in line, one conductor and one ground wire broken on one side of tower.
3. Span of 1,500 feet for wind and 5,700 feet for vertical loading, 17° angle in line and all wires broken on one side of tower.
4. Span of 1,500 feet for wind and 5,700 feet for vertical loading, 17° angle in line, and on one side of tower all wires broken, on other side of tower one outside conductor and one ground wire broken.

Weight of constant portion of tower with standard legs, pounds	14,836
Weight of steel in concrete footings, per tower, pounds	2,112
Quantity of concrete in footings, per tower, cubic yards	8.52
Number of towers	37

Type 5AH, Suspension Tower, Extra Insulation

Designed for light loading (8 pound wind at 25° F.):
1. Normal level span of 1,370 feet with an angle in the line of 2° 40'.
2. Maximum span of 1,940 feet with no angle in the line.
3. One broken conductor or one broken ground wire.

Weight of constant portion of tower with standard legs, pounds	10,682
Weight of steel in concrete footings, per tower, pounds	816
Quantity of concrete in footings, per tower, cubic yards	3.28
Number of towers	68
Number of towers with pile footings	24

All towers designed to withstand a wind pressure of 13 pounds per square foot on 1½ times the projected area of each tower face.

69-Kv Transmission Line

Towers

	Suspension	Dead End
Weight of constant portion of tower with standard legs, pounds	11,050	16,260
Weight of steel in concrete footings, pounds	788	2,112
Quantity of concrete in footings, cubic yards	2.92	8.52
Number of towers	7	6

References

1. Empirical Method of Calculating Corona Loss From High-Voltage Transmission Lines, Joseph S. Carroll and Mabel MacFerran Rockwell. Electrical Engineering, volume 56, pages 558–65.

2. Pull-in Characteristics of Synchronous Motors, D. R. Soults, A. H. Lauder, S. B. Crary. Electrical Engineering, volume 54, pages 1385–95.

3. Proposed Los Angeles-Colorado River Aqueduct, H. A. Van Norman. American Society of Civil Engineers, *Proceedings*, volume 54, number 4, April 1928, pages 1116–22.

4. Proposed Colorado River Aqueduct and Metropolitan Water District, F. E. Weymouth. American Society of Civil Engineers, *Proceedings*, part 1, August 1930, pages 1283–9.

5. Aqueduct Transmission Line to Carry Power to Pumps Near Completion. *Southwest Builder and Contractor*, volume 89, pages 12–14.

6. The Colorado River Aqueduct for Bringing Water to Southern California, E. E. Thomas. *General Electric Review*, volume 35, November 1932, pages 554–59.

7. Long Line Saves on Aqueduct Construction, J. M. Gaylord. *Electrical World*, volume 104, pages 615–17.

8. Colorado River Aqueduct, J. Hinds. *Military Engineer*, volume 24, number 134, March-April 1932, pages 115–19.

9. Great Job Looms in Colorado River Aqueduct, F. E. Weymouth. *Engineering News-Record*, volume 108, number 24, June 16, 1932, pages 947–50.

10. Construction Water Supply for Colorado River Aqueduct, J. Hinds. *Engineering News-Record*, volume 112, number 1, January 4, 1934, pages 13–16.

11. Colorado River Aqueduct Tunnels, J. L. Burkholder. *Civil Engineering*, volume 5, number 9 and 10, September 1935, pages 524–7, and October, page 643.

12. Hydraulic-Machinery Laboratory at California Institute of Technology, R. T. Knapp. American Society of Mechanical Engineers, *Transactions*, volume 58, number 8, November 1936, pages 663–76.

13. Colorado River Aqueduct Makes Rapid Progress, F. E. Weymouth, J. Hinds, J. L. Burkholder, and J. C. Agnew. *Civil Engineering*, volume 8, number 2, February 1935, pages 72–86.

14. Colorado River Water for California, J. Hinds. *Civil Engineering*, volume 7, August 1937, pages 573–5.

15. Developing High Efficiencies in Large Single-Stage Pumps, J. M. Gaylord. *Engineering News*, volume 118, January 14, 1937, pages 45–49.

16. Pumping Stations on the Colorado River Aqueduct, M. Spillman. American Water Works Association *Journal*, volume 28, November 1936, pages 1786–92.

17. The Insulator String, Royal W. Sorensen. Electrical Engineering, volume 53, August 1934, page 1221.

Discussion

R. W. Sorensen (California Institute of Technology and Board of Consulting Engineers for The Metropolitan Water District of Southern California): Mr. Gaylord's paper, so ably presented by Mr. Peabody, sums up a most unique and gargantuan project; namely, that of lifting a river of no mean size over 1,600 feet in an upward direction in order that the water of this river might flow steadily from the Colorado River along a 300-mile course to Southern California.

At first glance, one may say why are electrical engineers so much interested in a pumping system? But after all, such a system is made possible only by the availability of a perfectly enormous amount of electric power, over 300,000 kilowatts or one-third the firm power developed at Boulder Dam. Because Mr. Peabody has had a large part in the development of the pumps, and because the unique improvements made therein by research work are so striking and important, he has perhaps left in your minds the idea that the electrical features of this great project may have been somewhat secondary. Such, however, is not the case. Many factors of importance, such as the almost unparalleled management of the general manager and chief engineer, Dr. Frank E. Weymouth, and the work of the many engineers who have carried on the details, as well as the wholly voluntary and extraordinary services of the Board of Directors—have all contributed to an accomplishment, almost complete, of heretofore unprecedented dimensions. For example, this enormous project, costing $220,000,000 is being completed inside the original bond issue. This feature is due to careful analysis of problems of which we may take the transmission line as an example.

A study of the materials used in that line, as given in the paper, shows that high-quality work has been done throughout, but that no overconstruction has been used. For example, the line is built to have a few outages per year; because such outages do no particular harm, they simply result in stopping the flow of water for a short time, which for many years will be immaterial. Thus we find the cost of line necessary to be only about $9,500 a mile, which is indeed a low price for a 230-kv line. Speaking of transmission lines, may I say that in planning these lines some exceedingly interesting problems were encountered.

Before any construction could be started a desert had to be made habitable. In order to do this electric power for construction purposes was provided throughout the length of the aqueduct by running a 69,000-volt line from Colton to the Colorado River, a distance of about 250 miles. Those of you who are interested in transmission lines can readily appreciate the problems pertaining to stability and other features involved in such a line. Like problems are, of course, encountered in the 230-kv line installed permanently for pumping, because it is quite evident that one cannot design a line by simple rule-of-thumb methods and expect that line to perform satisfactorily when the huge motors used are started unless special consideration is given to motors, generators, and line so all factors will work together for such extreme conditions.

I have enjoyed greatly my contact with Mr. Gaylord and the rest of the staff of The Metropolitan Water District of Southern California, because it has been a pleasure to help them analyze with great care each order for machinery, transmission-line conductor, insulators, etc., in a way which would assure for every part of the job the best possible solution at the lowest cost consistent with the kind of construction needed. Nearly all of the equipment described is now installed. In a few months operation will start and, after a reasonable time has elapsed, I expect Mr. Gaylord or some of his staff will be able to present a most interesting paper on the electrical operation of the system.

In the meantime I think the report made in the paper concerning this particular type of application of electric energy is a record worthy of attention as an example of how dependent we are upon electrical power transmission for, without that possibility, the Colorado River Aqueduct of the Metropolitan Water District would have been much more difficult to construct and operate—if not wholly impossible.

Narrow-Band Transmission System for Animated Line Images

By A. M. SKELLETT
NONMEMBER AIEE

Synopsis: A method of transmission and reproduction of line images is described which utilizes a cathode-ray tube for reproduction, the spot of which is made to trace out the line image 20 or more times a second. In an experimental test, a drawing of a woman's head was reproduced with an equivalent total band width of approximately 2,600 cycles. This was made up of two bands, each 1,300 cycles wide for the potentials to the two sets of cathode-ray deflector plates. Analysis of a more complex image, such as that of an animated cartoon shows that such material could be transmitted and reproduced by this method within a total band width of 10,000 cycles.

Means are described for transcribing from drawing or animated cartoon film into recordings (similar to sound recordings) from which the potentials for transmission and subsequent operation of the cathode-ray tube may be obtained.

IT IS inherent in the systems of television on which work is being most actively pursued, that high definition must at all times be realized, no matter how simple the transmitted image may be. Yet many useful images do not contain a great amount of detail and in sending them large blank areas on the available field will be wastefully transmitted. A line drawing or an animated cartoon is an example of such a simple image. If it were possible to transmit the figure and line background, without the blank areas, a great simplification would occur. The system proposed herein was designed to take advantage of this fact.

By the application of proper potentials the bright spot of a cathode-ray tube may be made to traverse any path desired. Furthermore, if the spot is made to follow a certain path, such as that shown in figure 1, over and over, 20 or more times a second, this trace will produce on the end of the tube a stationary image as in figure 2.

Two potentials, each varying with time, are needed properly to actuate the spot. They are applied, the one across the horizontal and the other across the vertical set of plates of the cathode-ray tube. They are directly proportional, respectively, to the x and y co-ordinates of the points of the figure (for example, points 1, 2, 3, etc., of figure 1) taken along the path of the spot in the direction in which it moves. These potentials for the image of figure 1 are shown in graph form in figure 3.

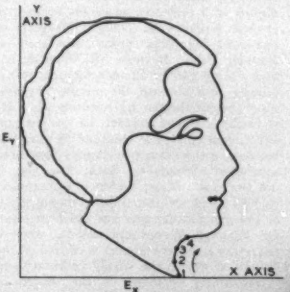


Figure 1. Resolution of a simple image into a single line. Total band needed for transmission: 2,000 cycles

Experimental Apparatus

The reproduction of figure 1 shown in figure 2 was obtained as follows: The x and y co-ordinates were plotted in polar co-ordinate form [$r = (a + x)$ or $(b + y)$, $\theta = t$] in concentric tracks one inch wide on a cardboard disk 12 inches in diameter. The area under each curve, that is, between the x curve and $r = a$ and between the y curve and $r = b$, was then blackened, and a negative photostat made of it. See figure 4. This disk was mounted on the shaft of a variable-speed motor so that it could be rotated 20 times a second or more and brightly illuminated.

A lens and a radially oriented slit were arranged in such a manner that a portion of the image of the x track fell across the slit. Behind it a photoelectric cell received the illumination passing through the slit. Thus the output of the photocell was directly proportional to the x co-ordinate at each instant of time. A similar setup, mounted alongside, gave potentials proportional to the y co-ordinates.

These two potentials were amplified through separate identical amplifiers and sent over two pairs of wires to the cathode-ray tube.

The method just described of recording the X and Y potential tracks on a disk is suitable for a single drawing but not for animated drawings. For these a record on a long ribbon or film is more practicable.

A device which transcribes from drawings into X and Y potential tracks is called a "transcriber" and the apparatus for obtaining these potentials from the recorded tracks is called the "converter." In figure 5 the complete process from image to image is shown in schematic form, the recordings in this case being on film.

Band Width

For the simplest type of image in which the drawing may be resolved into a single unbroken line, for example, figure 1, the total frequency spectrum or band width needed will consist of the sum of the band widths needed to transmit accurately the X and Y potentials. These may be assumed to be equal. The band width may then be determined by the analysis of the X (or Y) potential variations of a single trace by means of harmonic analysis.

The magnitude of this potential E may be expressed as a function of time by a

Figure 2. Photograph of an image reproduced by the first experimental setup. The chief differences between this image and that of figure 1 (from which the recorded tracks were obtained) were traced to errors in the recording

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Fourier equation with a sufficient number of terms.

$$E = f_1 \int_0^{\frac{1}{f_1}} E\,dt + \sum_{n=1}^{\infty} A_n \sin(\theta + \phi_n) \quad (1)$$

Here f_1 is the fundamental or trace frequency (about 20 per second) and A_n and ϕ_n are the amplitude and phase angle of the nth harmonic.

For any drawing the problem becomes that of determining the highest value of n needed for satisfactory reproduction. The band width will be that included between f_1 and the frequency of this nth component. The band-width will vary with f_1 for equal fidelity of reproduction. For instance if f_1 is increased to 30, then exactly the same image will be obtained with a band width from 30 to 3,000 cycles as would be realized with one from 20 to 2,000 cycles.

In general the two kinds of detail which will suffer most apparently by the elimination of higher order terms are straight portions and sharp bends. The over-all shape and form of the image and the larger details are dependent on the lower frequencies in the bands. These frequencies are therefore the most important

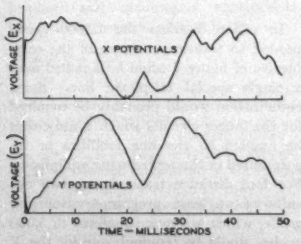


Figure 3. Potential variations needed to reproduce figure 1 on cathode-ray tube

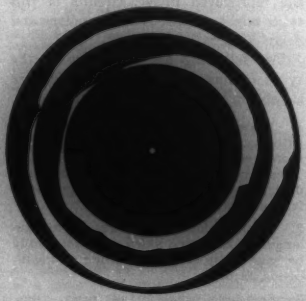


Figure 4. X and Y potential tracks used in reproducing figure 3

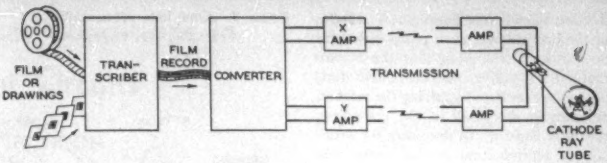


Figure 5. Schematic diagram of complete apparatus

ones. If the bands include enough harmonics to reproduce small details, even in approximate form, the larger details and general form will be reproduced with good fidelity. Thus the band width is largely determined by the fidelity of small detail desired.

Suppose we pick out the smallest detail, in the form of a sharp bend or kink in the curve of a potential function and attempt to determine the minimum frequency needed to reproduce it in approximate form. A little experience in harmonic analysis of typical forms will enable one to determine this frequency by inspection. Generally speaking it will be that frequency the sine wave of which can be made to fit most closely the general shape of the detail. For instance, for a sharp corner, the shape of the wave will determine the curvature that the corner will have when it is reproduced. If the band width extends up to and includes this frequency the detail in the image which gave rise to that in the potential curve will, in general, be reproduced in approximate form. The band width determined in this manner may, therefore, be taken as that necessary for satisfactory reproduction.

A rough check was obtained on the adequacy of this approximate method of analysis by equivalently narrowing the band width of the apparatus used in the reproduction of figure 2. The total band width determined as above for this figure was 2,000 cycles (1,000 cycles for each band). The bands passed by the amplifiers were equivalently reduced to 1,300 cycles each by speeding up the converter and no marked change in the image occurred.

Dark Paths

For all but the simplest of figures it will be necessary for the spot to traverse paths in the field along which the spot must not be visible. There are two methods of accomplishing this: (1) the beam can simply be cut off by a negative potential applied on the modulating cylinder as the spot passes over such dark paths or (2) it may be made to traverse

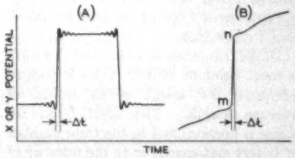


Figure 6. Typical wave forms generated in turning the spot on or off

them so quickly that the visibility of the trace is negligible.

For the first method an additional signal channel is needed and if its band width is made equal to that of the X or Y potential channels, the spot may be turned on or off in an amount of time somewhat less than that required to trace out the finest detail. The wave form would have the general form shown in figure 6*a* and the highest frequency f_n would be given by

$$f_n = \frac{1}{2\Delta t} \quad (2)$$

For the second method, that is, that of speeding up the spot over dark paths, the wave form required will be in the simplest case similar to that shown between m and n in figure 6*b*. The sharpness of the corners at m and n is determined by the upper frequency limit of the system.

Actually this method requires that either or both the X and Y potentials suddenly change in value so that the spot will abruptly jump across the dark path at such a speed that it is not visible. In figure 2, the velocity of the spot was deliberately increased by a factor of 5 in tracing the line across the neck. A velocity at least twice as great as this is required to make the trace effectively invisible.

Thus it appears that this latter method is to be preferred in general since it requires no increase in band width and no extra channel with its extra facilities.

A cartoon of Walt Disney's popular figure was chosen for determining the frequency band required to reproduce a sketch of considerable complexity. This was resolved into one continuous line such as would be followed by the cathode-ray spot for reproduction. This repro-

duction would look like figure 7. Parts of the line are over dark paths which are not shown. Assuming that the second method of taking care of these dark paths were used and applying the method of analysis described in the preceding, the total band width necessary for satisfactory reproduction of this image was judged to be 10,000 cycles. This total is made up of 5,000 cycles each for the X and Y potentials.

In the transmission of writing or script, a total band of 10,000 cycles is judged adequate for about seven words of average length. The total band for script is proportional to the total number of letters and spaces or to the number of words of average length.

The Centering Coefficient

The first term of the series of equation 1 is of importance in centering the image in the field. It is

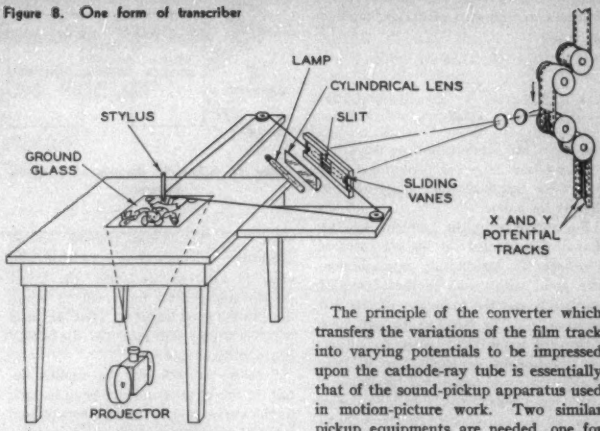
$$f_1 \int_0^{\frac{1}{f_1}} E \, dt$$

This is simply the total area of the curve over one cycle of period $1/f_1$ divided by the base line $1/f_1$. It thus represents the mean distance of the curve from the zero

Figure 7. Total band needed for transmission of this image is 10,000 cycles wide. The spot will move one-half as fast over the figure as it does over the background

axis. If eliminated, the shape of the curve and hence also of the image would not be altered, but the centering of the image would vary as the figures moved around in the field. As an example of the effect of this, suppose that the image consisted of a central figure of some complexity and a very simple background. Then if the figure started to walk from the center to the side of the field, the absence of the transmission of this component would hold the figure near the

Figure 8. One form of transcriber



center and the background would slide away in the opposite direction.

Ordinarily this component would be eliminated by the apparatus since it gives rise mainly to a direct current. It presents a similar problem in television where it determines the general brightness of the background. Several schemes have been devised to reintroduce or to compensate for it in television and some of these might be used here also. If the image frequencies are used to modulate a carrier, the band may be made to extend to zero on the low-frequency end and this component will then be included in the transmission. The particular method used will depend on the transmission system.

The Transcription Process

In order to get the X and Y potential recordings, some means of transcribing the original drawings or images into these potential recordings is needed. The simplest method at present seems to be one in which a stylus is manually made to follow the lines of the drawing. This stylus would be coupled up mechanically or electrically with suitable apparatus whose function would be to record simultaneously on film or other media, two tracks, the amplitudes of which would be proportional, respectively, to the X and Y co-ordinates of the various positions of the stylus. Such a machine is shown in simplified form in figure 8. It is arranged to transcribe directly from the film of an animated cartoon. The projector throws onto the ground glass one frame of the film at a time, and the stylus is moved by the operator over the lines of the image.

The principle of the converter which transfers the variations of the film track into varying potentials to be impressed upon the cathode-ray tube is essentially that of the sound-pickup apparatus used in motion-picture work. Two similar pickup equipments are needed, one for the X and one for the Y potential track. If there is a sound track to accompany the cartoon, a third equipment will be needed for it. The standard speed of 90 feet per minute for the film is adequate since with the usual types of pickup this allows a band width of about 6,000 cycles.

Applications

In urban districts the 10,000 cycles needed to transmit a figure of the complexity of figure 7 could be handled over a single special telephone line. Some equalization would probably be required for the longer circuits which could either be applied to the line facilities or incorporated in the reproducing equipment. For long-distance transmission two circuits of at least program-transmission grade, which are now equalized to 5,000 cycles, would be required, one for the X and one for the Y potentials. Depending upon the degree of definition desired in the reproduced image, circuits of this type might require some supplemental delay equalization.

The following are exemplary of the types of image transmission which are capable of transmission by this method:

1. Drawings, diagrams, and maps either with or without animation, animated cartoons, etc., of purely commercial value. These might include animated drawings depicting the working of new equipment, fashion sketches, etc.

2. Script, including signatures and foreign-language characters, which could not readily be handled by ordinary existing communication facilities.

3. Sketches, primarily of news value. These would include drawings of famous people, places, ceremonies, fashions, and

Similitude of Critical Conditions in Ferroresonant Circuits

By WILLIAM T. THOMSON
ASSOCIATE AIEE

RECENTLY a number of articles dealing with the critical conditions in ferroresonant circuits has appeared. However, no simple generalization is possible from these previous methods. The generalization presented in this paper offers certain information pertaining to similitudes of circuits in a surprisingly simple manner. Knowing the critical stable conditions for one reactor, the principle of similitude enables the predetermination of the critical stable conditions for any other reactor using the same grade of iron.

Equation for Critical Conditions

The circuit referred to in this investigation is one containing a resistance, a condenser, and a saturable-core reactor as shown in figure 1. Assuming that the applied voltage can be resolved into the in-phase and quadrature components, the following vector relation holds:

$$E^2 = E_X^2 + E_R^2 \tag{1}$$

where

E = applied voltage
E_X = $(E_{LX} - E_C)$ = reactive voltage
E_R = $(E_{LR} + E_{RO})$ = in-phase voltage
E_{LX} = reactive component of the reactor voltage
E_{LR} = in-phase component of the reactor voltage

The critical conditions are defined as points on the volt-ampere curve where $dE/di = 0$. Since $dE/d\left(\frac{ni}{l}\right)$ also equals zero for these points,

$$2E\frac{dE}{d\left(\frac{ni}{l}\right)} = 2E_X\frac{dE_X}{d\left(\frac{ni}{l}\right)} + 2E_R\frac{dE_R}{d\left(\frac{ni}{l}\right)}$$

or

$$E_X\frac{dE_X}{d\left(\frac{ni}{l}\right)} = -E_R\frac{dE_R}{d\left(\frac{ni}{l}\right)} \tag{2}$$

For the unstable condition the above relation is satisfied by two values of current or ampere-turns per inch, while for the critical stable condition the two values of ampere-turns per inch approach a single value.

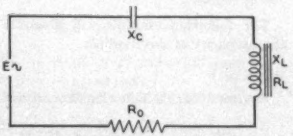


Figure 1. Ferroresonant series circuit

The Generalized Equations

It now becomes necessary to express E_X and E_R in general terms. For simplicity the following assumptions will be made:

$$E_{LR} = \frac{W}{i_1} \tag{3}$$

$$E_{LX} = \sqrt{E_L^2 - \left(\frac{W}{i_1}\right)^2} \tag{4}$$

where

W = iron losses of the reactor with sine wave of impressed voltage
i_1 = root-mean-square value of the fundamental current.

Since the reactive component of the reactor voltage is proportional to the maximum flux density, which in turn is a function of the ampere-turns per inch,

$$E_{LX} = 4\gamma f n A B_{max} \times 10^{-8} = n A \beta \tag{5}$$

where

$\beta = 4\gamma f B_{max} \times 10^{-8}$ = a function of $\left(\frac{ni}{l}\right)$
n = number of turns on the reactor
A = cross section area of the core
γ = form factor

The in-phase component of the reactor voltage is generalized as follows.

$$E_{LR} = nA\left\{\left(\frac{\rho}{Al}\right)\frac{\left(\frac{W}{\rho}\right)}{K\left(\frac{ni}{l}\right)}\right\} = nA\left\{\rho\frac{\left(\frac{W}{\rho}\right)}{K\left(\frac{ni}{l}\right)}\right\} = nA\alpha \tag{6}$$

where

ρ = density of iron used
$\left(\frac{W}{\rho}\right)$ = watts per pound = a function of B_{max} therefore a function of $\left(\frac{ni}{l}\right)$
$K = \frac{i_1}{i}$ = ratio of the fundamental to effective current

Since β and α are single curves for any given iron when plotted against the ampere-turns per inch, the two component voltages of the reactor are completely generalized. The values of β and α may be obtained experimentally by dividing E_{LX} and E_{LR} as found from (3) and (4) by nA of the reactor; however, these curves are not necessary for the solution of the critical stable condition.

It is now possible to express E_X and E_R as follows:

$$E_X = nA\beta - \left(\frac{ni}{l}\right)\frac{X_C}{\left(\frac{n}{l}\right)} \tag{7}$$

$$E_R = nA\alpha + \left(\frac{ni}{l}\right)\frac{R_O}{\left(\frac{n}{l}\right)} \tag{8}$$

where R_O = series resistance of the cir-

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sketches made by an artist at the location of a news event such as a trial, football game, etc. This last would require a transcriber somewhat different from those described above in that it would have to convert the motion of the artist's stylus immediately into the proper pulsating potentials for sending the image simultaneously with the drawing of it. There are several possible means of doing this.

cuit. Substituting into equation (2)

$$\left\{nA\beta - \left(\frac{ni}{l}\right)\frac{X_c}{\left(\frac{n}{l}\right)}\right\} \times \left\{nA\frac{d\beta}{d\left(\frac{ni}{l}\right)} - \frac{X_c}{\left(\frac{n}{l}\right)}\right\} = -\left\{nA\alpha + \left(\frac{ni}{l}\right)\frac{R_o}{\left(\frac{n}{l}\right)}\right\} \times \left\{An\frac{d\alpha}{d\left(\frac{ni}{l}\right)} + \frac{R_o}{\left(\frac{n}{l}\right)}\right\}$$

Dividing through by $(nA)^2$

$$\left\{\beta - \left(\frac{ni}{l}\right)\left(\frac{X_c}{\frac{n^2A}{l}}\right)\right\} \times \left\{\frac{d\beta}{d\left(\frac{ni}{l}\right)} - \left(\frac{X_c}{\frac{n^2A}{l}}\right)\right\} = -\left\{\alpha + \left(\frac{ni}{l}\right)\left(\frac{R_o}{\frac{n^2A}{l}}\right)\right\} \times \left\{\frac{d\alpha}{d\left(\frac{ni}{l}\right)} + \left(\frac{R_o}{\frac{n^2A}{l}}\right)\right\} \quad (9)$$

Equation (9) is the generalized equation for the critical conditions of the circuit. In this β, α, $d\beta/d\left(\frac{ni}{l}\right)$ and $d\alpha/d\left(\frac{ni}{l}\right)$ have a definite value for any given value of $\left(\frac{ni}{l}\right)$, regardless of the reactor used; therefore the solution of equation (9) will depend only on the values of $X_c \Big/ \frac{n^2A}{l}$ and $R_o \Big/ \frac{n^2A}{l}$.

By substituting (7) and (8) in equation (1), the generalized expression for the voltage becomes

$$\left(\frac{E}{nA}\right)^2 = \left\{\beta - \left(\frac{ni}{l}\right)\left(\frac{X_c}{\frac{n^2A}{l}}\right)\right\}^2 + \left\{\alpha + \left(\frac{ni}{l}\right)\left(\frac{R_o}{\frac{n^2A}{l}}\right)\right\}^2 \quad (10)$$

The Principle of Similitude of Circuits

From equations (9) and (10) it is possible to draw certain conclusions. The following apply to the critical stable condition:

1. Two different circuits with equal values of $X_c \Big/ \frac{n^2A}{l}$ will have equal values of $R_o \Big/ \frac{n^2A}{l}$ and the ampere-turns per inch for the critical stable condition will be equal.

2. For the case above the values of E/nA for the two circuits will be equal.

3. Since the values of n, A, and l are generally known for any reactor, it is possible to predetermine the critical stable values of X_c, R_o, i, and E for any reactor by a very simple process.

4. The critical values of $R_o \Big/ \frac{n^2A}{l}$, E/nA, and $\frac{ni}{l}$ when plotted against $X_c \Big/ \frac{n^2A}{l}$ are a function only of the type of iron used. (See figure 4.)

5. From the four generalized terms above it is seen that the vector voltage triangles for two similar circuits will be similar; therefore with equal ampere-turns per inch as found under similar conditions the wave shapes of the voltage across the reactors as well as that of the current will be equal. It is then possible to state that under similar conditions in two reactors with the same grade of iron, each unit volume of iron goes through the same cycle wave shape and all.

Illustrative Example

The following example will illustrate the simplicity of this method:

PROBLEM 1

Reactor 1 has the following dimensions:

n	= 520	$\frac{n^2A}{l}$	= 45,700
A	= 2.62 square inches	nA	= 1,360
l	= 15.5 inches	$\frac{n}{l}$	= 33.5

When operated in a series circuit with X_C = 272 ohms, it gave the following values for the critical stable condition (see figure 2):

R_o = 145 ohms
E = 224
i = 0.52

What will be the corresponding critical stable values for reactor 2 with the following dimensions?

n	= 352	$\frac{n^2A}{l}$	= 17,400
A	= 1.72	nA	= 605
l	= 12.25	$\frac{n}{l}$	= 28.7

SOLUTION

$$\left(\frac{X_c}{\frac{n^2A}{l}}\right)_1 = \left(\frac{X_c}{\frac{n^2A}{l}}\right)_2$$

$$\frac{272}{45{,}700} = \frac{X_{c_2}}{17{,}400} \quad \therefore X_{c_2} = 104 \text{ ohms}$$

$$\left(\frac{R_o}{\frac{n_2A}{l}}\right)_1 = \left(\frac{R_o}{\frac{n^2A}{l}}\right)_2$$

$$\frac{145}{45{,}700} = \frac{R_{o_2}}{17{,}400} \quad \therefore R_{o_2} = 55.1 \text{ ohms}$$
Exp. value = 53 ohms

$$\left(\frac{E}{nA}\right)_1 = \left(\frac{E}{nA}\right)_2$$

$$\frac{224}{1{,}360} = \frac{E_2}{605} \quad \therefore E_2 = 99.5 \text{ volts}$$
Exp. value = 100 volts

$$\left(\frac{ni}{l}\right)_1 = \left(\frac{ni}{l}\right)_2$$

$$33.5 \times 0.52 = 28.7 \times i_2$$
$$\therefore i_2 = 0.607 \text{ ampere}$$
Exp. value = 0.61 ampere

This procedure is repeated for other values of X_c. The dotted curves of figure 3 shows the critical stable values for reactor 2 predetermined from the experimental values of reactor 1. The discrepancies are due mainly to differences in the flux leakages of the two reactors.

The Generalized Curves

The critical stable condition for any series circuit can be generalized in terms of $X_c \Big/ \frac{n^2A}{l}$, $R_o \Big/ \frac{n^2A}{l}$, E/nA, and $\frac{ni}{l}$. Figure 4 calculated from four different reactors indicates good agreement with the theory. The tabulated values for the curves are given in table I.

From such a curve it is possible to determine the critical stable values for any reactor almost immediately. To illustrate its use a typical problem will be taken.

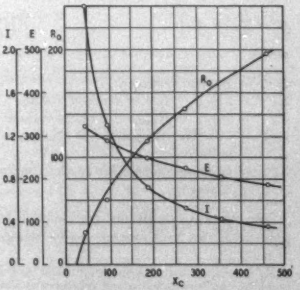

Figure 2. Critical stable values for reactor 1

PROBLEM 2

It is desired to design a voltage-sensitive circuit with a critical stable voltage of 200 volts and a critical stable current of 0.6 ampere.

This may be accomplished in a number of different ways. However, from the practical viewpoint the problem is fairly well limited. Starting with a certain value of $X_c \Big/ \frac{n^2A}{l}$ the reactor dimensions and the condenser size can be determined. If these values are un-

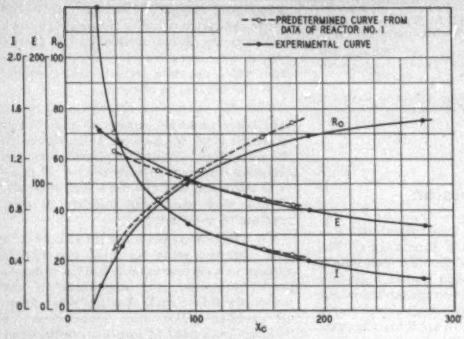

Figure 3. Critical stable values for reactor 2

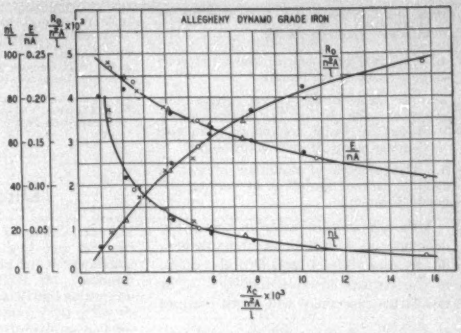

Figure 4. Generalized curves for the critical stable condition

$$\frac{E}{nA} = 0.187 \quad \therefore nA = \frac{200}{0.187} = 1{,}070$$

$$\frac{ni}{l} = 26.5 \qquad \frac{n}{l} = \frac{26.5}{0.6} = 44.2$$

$$Al = \frac{1{,}070}{44.2} = 24.2 \text{ cubic inches}$$

$$\frac{n^2A}{l} = 44.2 \times 1{,}070 = 47{,}300$$

$X_C = 0.004 \times 47{,}300 = 190$ ohms

$C = 14$ microfarads

$R_O = 0.0023 \times 47{,}300 = 109$ ohms

If

$l = 12$ inches

$A = 2.02$ square inches

$n = 530$ turns

These values are within the practical range. If a still smaller reactor is desired, a smaller value of $X_C \Big/ \frac{n^2A}{l}$ should be chosen, the size of the core being limited by the space necessary for the coils.

practical, another value of $X_C \Big/ \frac{n^2A}{l}$ is chosen and the process repeated.

Starting with $X_C \Big/ \frac{n^2A}{l} = 0.010$

$$\frac{E}{nA} = 0.135 \quad \therefore nA = \frac{200}{0.135} = 1{,}470$$

$$\frac{ni}{l} = 12 \qquad \frac{n}{l} = \frac{12}{0.6} = 20$$

$$\text{Volume} = Al = \frac{1{,}470}{20} = 73.5 \text{ cubic inches}$$

This would result in a bulky reactor; therefore, start with a smaller value of $X_C \Big/ \frac{n^2A}{l}$.

For

$$\frac{X_C}{\frac{n^2A}{l}} = 0.004$$

Table I. Generalization of the Critical Stable Values

		Experimental Values				$\frac{X_C}{\frac{n^2A}{l}}$	$\frac{R_O}{\frac{n^2A}{l}}$	$\frac{E}{nA}$	$\frac{ni}{l}$	
		X_C	R_O	E	i					
Reactor 1		43.	30.	323.	2.4	0.00094	0.000656	0.237	80.5	$\frac{n^2A}{l} = 45{,}700$
n = 520		93.	60.	284.	1.3	0.00204	0.00131	0.209	43.5	$nA = 1{,}360$
A = 2.62	●	188.	114.	248.	0.72	0.00412	0.00250	0.182	24.1	$\frac{n}{l} = 33.5$
l = 15.5		272.	145.	224.	0.52	0.00595	0.00317	0.165	17.4	
		355.	170.	205.	0.43	0.00778	0.00372	0.151	14.4	
		460.	195.	186.	0.36	0.0101	0.00426	0.137	12.1	
Reactor 2		25.	10.	142.	2.4	0.00144	0.000575	0.234	69.0	$\frac{n^2A}{l} = 17{,}400$
n = 352		43.	26.	132.	1.3	0.00247	0.00149	0.218	37.3	$nA = 605$
A = 1.72	⊙	93.	50.	104.	0.68	0.00535	0.00287	0.172	19.5	$\frac{n}{l} = 28.7$
l = 12.25		187.	68.	78.	0.40	0.0107	0.00390	0.129	11.5	
		272.	75.	66.	0.25	0.0156	0.00430	0.109	7.2	
Reactor 3		93.	63.	290.	1.3	0.00134	0.000905	0.240	74.6	$\frac{n^2A}{l} = 69{,}700$
n = 704		187.	120.	252.	0.68	0.00268	0.00173	0.208	39.0	$nA = 1{,}210$
A = 1.72	×	272.	164.	230.	0.50	0.0039	0.00235	0.190	28.7	$\frac{n}{l} = 57.4$
l = 12.25		355.	182.	209.	0.40	0.0051	0.00261	0.173	23.0	
Reactor 4		93.	56.	252.	1.13	0.00202	0.00122	0.223	46.1	$\frac{n^2A}{l} = 46{,}000$
n = 500		187.	107.	212.	0.62	0.00406	0.00232	0.188	25.3	$nA = 1{,}125$
A = 2.25	▲	272.	139.	188.	0.48	0.00590	0.00302	0.167	19.6	$\frac{n}{l} = 40.8$
l = 12.25		339.	158.	172.	0.40	0.00738	0.00344	0.153	16.3	

Equivalent Series Circuits

The generalized treatment so far has dealt only with the series circuit. However, the same principle can be used for other circuits by reducing them to the equivalent series circuit.

One practical application of such a scheme is found in the design of the resonant relay circuits. By shunting a high-impedance relay across the condenser of the ferroresonant circuit, relays which normally release at half the closing voltage can be made to open and close at the same voltage when the circuit is tuned for the critical stable condition.

In order to make use of the generalized chart it is now necessary to use the equivalent series reactance and resistance of the circuit. For a relay across the condenser the equivalent series values reduce to a capacity reactance of

$$X_C' = X_C \left\{ \frac{r^2 + X_R(X_R - X_C)}{r^2 + (X_R - X_C)^2} \right\} \qquad (11)$$

and a resistance of

$$R' = r \left\{ \frac{X_C^2}{r^2 + (X_R - X_C)^2} \right\} \qquad (12)$$

where

X_C = reactance of the condenser used

r = resistance of the relay

X_R = average reactance of the relay

Conclusion

The principle of similitude offers the simplest and the most practical solution for the critical conditions of the ferro-

resonant circuit. Some of the advantages over previous methods are:

1. It is not necessary to know the volt-ampere curve of the reactor.

2. The generalized curves giving the complete solution for the critical stable condition are easily determined from any test reactor using the same grade of iron.

3. The principle of similitude presents a clear picture of the effect of varying the circuit parameters.

Although the discussion in this paper dealt mainly with the critical stable condition, equations (9) and (10) also apply to the critical unstable condition. For this latter case there will be two values of $\left(\frac{ni}{l}\right)$, and they will be completely specified by the values of $X_c \Big/ \frac{n^2 A}{l}$ and $R_o \Big/ \frac{n^2 A}{l}$.

References

1. Über neue Resonanzerscheinungen in Wechselstromkreisen, O. Martienssen. *Physik. Zeits.*, volume 11, May 1910, pages 448–60.

2. Über Schwingungskreise mit Eisenkernspulen, H. Schunck and J. Zenneck. *Jahrb. d. dr. Tel. u. Tel.*, volume 19, 1922, pages 170–94.

3. Ueber die selbsterregten in Kreisen mit Eisenkernspulen, H. Winter-Gunther. *Jahrb. d. dr. Tel. u. Tel.*, volume 34, 1929, pages 41–9.

4. Studies in Nonlinear Circuits, C. G. Suits. AIEE Transactions, June 1931, pages 734–36.

5. Mathematical Analysis of Nonlinear Circuits, A. Boyajian. *General Electric Review*, September 1931, pages 531–7; December 1931, pages 745–51.

6. Nonlinear Circuits Applied to Relays, C. G. Suits. Electrical Engineering, April 1933, pages 244–6.

7. Contribution a l'etude experimentale de la ferro-resonance, R. Roulle. *Revue Gen. de l'Electricité*, November 1934, pages 715–38; December, pages 753–80, 795–819, 841–58.

8. Direct-Current-Controlled Reactors, C. V. Aggers and W. E. Pakala. *Electric Journal*, February 1937, pages 55–9.

9. The Alternator Voltage Regulator Utilizing a Nonlinear Circuit, H. W. Mayne. Electrical Engineering, April 1937, pages 462–5.

10. Subharmonics in Circuits Containing Iron, I. A. Travis and C. N. Weygandt. AIEE Transactions, volume 57, 1938, pages 423–31.

11. Critical Conditions in Ferro-Resonance, P. H. Odessey and E. Weber. AIEE Transactions, volume 57, 1938, pages 444–52.

12. Resonant Nonlinear Control Circuits, W. T. Thomson. AIEE Transactions, volume 57, 1938, pages 469–76.

Discussion

W. B. Coulthard (Department of Mechanical and Electrical Engineering, The University of British Columbia, Vancouver, Canada): Mr. Thomson makes a further interesting contribution on the ferroresonant circuit in predetermining the limits of stable conditions. However, in applying the principle of similitude to this circuit, care must be exercised.

My criticisms of this method are as follows:

1. The dimensions of the coils and cores must ensure proportionality between the leakage and iron flux.

2. The impedance of the source of supply must be considered. It is well known that different points of instability are obtained when the voltage is varied by controlling the excitation of the alternator and when it is varied by induction regulator control. So to apply the principle of similitude, identical supply circuits must be specified.

3. When reactance preponderates in the supply circuit, due to the phase shift the point of instability does not occur at the peak and dip of the *EI* characteristic but at some points beyond. Instability is now no longer defined by $\frac{dE}{dI} = 0$ but by $\frac{dE}{dI}$ = a negative quantity. Under critical stable conditions it appears that the *EI* characteristic is no longer parallel to the current axis, but there is a slight bend between what are defined as the low- and high-circuit regions. In these circumstances $\frac{dE}{dI} = 0$ does not hold.

W. T. Thomson: (1) In order to apply the principle of similitude to any physical problem, it is obvious that the two systems to be compared must be proportional in every way. The accuracy of predetermination will therefore depend on the degree to which this requirement is satisfied.

In ferroresonant circuits it would be impracticable to attempt perfect proportionality in design. However, one should insure similarity within a reasonable degree. For instance, if it is desired to use the *EI* type of core in the reactor, the test reactor from which the data must be taken, should have the same type of core.

The core of the four reactors used to obtain the generalized curves of figure 4 are of the *EI* type, the a-c coils being placed on the outer legs. Figure 4 indicates that the accuracy obtained is sufficient for all practical purposes, and the data should be applicable with reasonable accuracy to other reactors of the *EI* type.

2. The critical points of the circuit vary with different wave forms of the applied voltage to a certain extent, and for accurate predetermination, the impedance of the source should be such that the wave forms are similar. For this investigation a "Variac" was used to insure a minimum of wave distortion.

3. The critical stable condition was defined as the limiting condition of the equation $\frac{dE}{dI} = 0$, and $\frac{dE}{dI}$ equal to a negative quantity does not come under the case of critical stable operation.

For the unstable condition $\frac{dE}{dI} = 0$ will still be points of major interest regardless of whether they represent points of instability or not. With a supply of good regulation $\frac{dE}{dI} = 0$, will represent limiting points of instability.

In general by using reasonable care in insuring proportionality, the accuracy obtained will be sufficient for all practical purposes. It should also be pointed out that up to the present there has been no publication of any other method by which it is possible to predetermine accurately the critical points of ferroresonant circuits in a generalized manner. In articles dealing with ferroresonance, the problem has been turned around backwards, e.g., to calculate the critical points for a given circuit, while the information most desired is of the reverse order; i.e., to be able to start from some specified critical point and design the circuit to give this performance. The information enabling this predetermination must necessarily be of the generalized order such as the one discussed in this article.

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Industrial Notes

Mica Survey.—The United States Tariff Commission, Washington, D. C., has issued a report of nearly 300 pages concerning the mica industry of the world. Comprehensive data are given with respect to production, uses, and international trade in mica, including the effects of tariffs on such trade. The report also refers to the recent invention of a product made from colloidal clays like bentoite and reported to be similar to or identical with mica in its most important electrical properties. Considerable space has been devoted to explaining the functions of various types of mica in electrical appliances and apparatus. Sources of supply of electrical and other mica are included. A limited number of copies of the report (No. 130, Second Series) are available for distribution by the Tariff Commission, or the report may be purchased from the Superintendent of Documents, Washington, D. C., at 25 cents per copy.

Aerovox Opens New York Office.—Having recently moved its plant from Brooklyn, N. Y. to New Bedford, Mass., the Aerovox Corporation has now opened a New York City sales office at 347 Fifth Ave.

U.S. Rubber Appointment.—M. P. Lewis, former Eastern district manager, wire sales, United States Rubber Co., was recently appointed assistant manager of the wire sales department, with headquarters at the company's main office, 1790 Broadway, New York, N. Y.

General Electric Appointments.—V. A. Sheals has been named assistant designing engineer of the cable engineering department of the General Electric Co., Schenectady. F. D. Crowther has been appointed commercial assistant to A. F. Dickerson, manager of the illuminating laboratory and lighting sales section at Schenectady.

American Transformer Appointment.—M. D. Summer has been appointed by the American Transformer Co., Newark, N. J., as New England representative for the sale of distribution and power transformers and other products of the industrial transformer division. Mr. Summer, previously district manager of the company's transformer sales at Buffalo, N. Y., has opened an office at 99 Chauncey St., Boston.

Westinghouse Sales.—The Mansfield works of the Westinghouse Electric & Mfg. Co., shipped more electric refrigerators in January of this year than in any other similar month in the company's history, exceeding shipments for the entire first quarter of 1938. It is also believed a new record will be set for February sales. Normally, April and May are the months showing the greatest activity.

Large Orders to Allis-Chalmers.—Orders recently received by the Allis-Chalmers Mfg. Co., Milwaukee, include a contract of approximately $290,000 covering electrical equipment for the Indiana plant of the Youngstown Sheet & Tube Co. Two large motor generator sets rated at 6,000 kw each are included. Other equipment comprises three 3,333-kva, single-phase and a 1,500-kva, three-phase indoor transformer. The B. F. Sturtevant Company, of Boston, has ordered 18 large motors, 9 rated at 1,000 hp each and 9 at 400 hp each. All will be used to drive large fans for a Western utility.

Trade Literature

Testing Machines For Plastics.—Bulletin 17, 12 pp. Describes several types of machines for testing plastic materials; illustrated in two colors. Tinius Olsen Testing Machine Co., 500 No. 12th St., Philadelphia, Pa.

Air Conditioning.—Bulletin, 16 pp. Describes a new development in air conditioning, featuring chemical dehumidification. Research Corp., 405 Lexington Ave., New York, N. Y.

Thermometers.—Catalog 1170, 16 pp. Describes various types of dial-indicating thermometers for industrial use. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

Fans.—Catalog X3349, 28 pp. Describes various types of electric fans, including several new models; construction features, performance and prices are included. The Emerson Electric Mfg. Co., St. Louis, Mo.

Nickel.—Bulletin T-15, 20 pp. Contains extensive tabulated data on the mechanical properties and physical constants of nickel. Dev. and Research Div., International Nickel Co., Inc., 67 Wall St., New York.

Steam Turbines.—Bulletin B2175, 22 pp. Describes turbines in the 100 to 2,000-hp range, 1,000 to 5,500 rpm, for steam pressures up to 650 pounds, steam temperatures up to 750°. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Motors.—Bulletin 515, 4 pp., "Motor Application Chart." Lists 26 types of motors and checks the proper type of motor recommended for some 50 standard applications. Also analyzes the starting and full load torque characteristics, speed regulation, etc. The Louis Allis Co., Milwaukee, Wis.

Air-Operated Control Valves.—Bulletin 514, 20 pp. Describes air-operated synchro-valves for automatic control. These valves are for controllers of the pneumatic type, for pressure, flow, liquid level, temperature and humidity. The Bristol Co., Waterbury, Conn.

Fuse Cutouts.—Bulletin GEA 1993E, 12 pp. Describes enclosed, indicating and dropout fuse cutouts which, in either of two ways, give positive indication that the circuit is open whenever a fuse link is blown. General Electric Co., Schenectady, N. Y.

Control and Distribution Apparatus.—Cat. 391, 88 pp. Describes safety switches, service equipment, switchboards, light and power panelboards, bus distribution systems; also new "rocker" type safety switches and panelboards. Bull Dog Electric Products Co., Detroit, Mich.

Wide-Strip Pyrometers.—Bulletin 1452, 36 pp. Describes a line of wide-strip pyrometer recorders and controllers. Includes the fundamental principles of operation of these instruments and illustrates the various types of thermocouples and the charts, with ranges available. The Bristol Co., Waterbury, Conn.

Ground Rods.—Bulletin C-14, 20 pp. Describes solid copper star ground rods and Everdur ground wire clamps. Engineering data on grounds, soil resistivity and artificial soil treatment, methods of measuring ground resistance, etc., are outlined. Anaconda Wire & Cable Co., 25 Broadway, New York, N. Y.

Feeder-Voltage Boosters.—Cat. Sec. 47-225, 8 pp. Describes type BR two-step feeder-voltage boosters particularly applicable to rural lines or distribution circuits where the load changes once or twice daily from very light to nearly full load. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Rectifiers.—Bulletin 2343, 8 pp. Describes small capacity, permanently evacuated, glass bulb rectifier units recently made available. Illustrates the advantages of such equipment for use in small traction systems, industrial plants with moderate d-c power requirements, and large buildings affected by d-c to a-c changeovers. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Lift Platform Trucks.—Bulletin A-8416, 4 pp. Describes type EP-10 low lift platform trucks; Bulletin A-8459, 4 pp., describes type ELN-10 (high lift). Both trucks have rated capacities of 10,000 pounds and are equipped with controllers which permit four speeds forward and four reverse, and dynamic brakes. The Elwell-Parker Electric Co., Cleveland, O.

High-Line Poles.—Chart comprising a new compilation of test figures of strength and related properties of "Greenheart" and "Wallaba" woods as compared with certain American woods. Bulletin 19A, 12 pp., "Two Strong Woods Naturally Durable," describes self-impregnated termite-proof, tropical timbers,—products of British Guiana. Greenheart & Wallaba Timber Co., Inc., 52 Vanderbilt Ave., New York.

Thermocouple Temperature Indicators.—Cat. N-33A(5), 4 pp., "Manually-Operated Indicators for Thermocouple Temperatures." Includes a description of a new temperature indicator which may be installed wherever convenient. Ample space is provided for toggle-type switches, for connecting any one of a number of couples to the measuring circuit. Temperatures of near or distant couples may be measured with equal reliability by simply turning a knob until the pointer comes to zero, and reading a temperature scale. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

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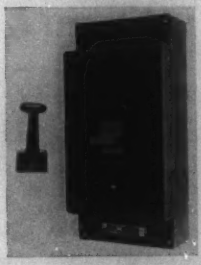
Inkless Recording Instruments.—Continuous accurate operation for 30 days without attention, at temperatures as low as −10° F and as high as 120° F, is made

possible by the new type CF-1 line of inkless recording single- and double-range a-c ammeters and voltmeters, announced by the General Electric Co., Schenectady, N. Y. The units are in the low-price range and are particularly well suited for voltage surveys, complaint investigations, and checking circuit load conditions. The inkless mechanism, which uses a typewriter ribbon to make the record by a series of dots, results in greater simplicity, small size, and light weight. Although they are portable, the new instruments may be wall- or pole-mounted. Voltmeters are listed for the double range of 0–140/0–280 volts. Ammeters are for 0–5/0–10 amperes. Single range instruments can also be supplied. The new line imposes an exceptionally low burden on instrument transformers—only 1 volt-ampere for the 5-ampere ammeter or the 140-volt voltmeter at 60 cycles.

Midget Relays.—A new line of midget, mechanical latch-in, electrical reset relays made in both a-c—110–220 volts, 6 and 3 amperes, respectively; and in d-c—115

volts, 1 ampere, have been placed on the market by Struthers Dunn, Inc., Philadelphia, Pa. They are provided with two coils. When the lower coil is energized, the armature picks up and latches in the energized position. Energizing the upper coil releases the latch allowing the armature to drop out. These relays are used in connection with three-wire thermostats, push buttons, etc.

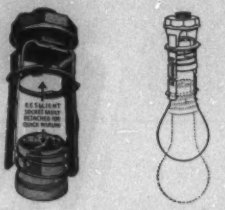
Air Circuit Breaker.—Type ET-20, general-purpose, air circuit breakers developed by the I-T-E Circuit Breaker Co., Philadelphia, Pa., are intended primarily for use in panelboards and for circuit protection of main distribution feeders in switchboards where concentration of power requires a breaker of 20,000-ampere interrupting capacity. The unit is readily convertible to either front or rear connection. The poles



open and close simultaneously and are operated by a single handle. Each pole is equipped with an inverse time thermal overload and an instantaneous magnetic trip feature, both operating on a common trip so that an overload on any pole opens the breaker. The trip units are interchangeable and are calibrated and contained within a sealed case. The instantaneous trip features are calibrated at six to eight times the rating of the circuit breaker.

Permanent Chart for Recorders.—A new permanent chart for recording meters, impervious to moisture and unaffected by atmospheric changes, has been introduced by the Permochart Co., Pittsburgh, Pa. Each day's recordings are easily removed by use of a damp cloth and the same chart is used over and over again. The chart, known as "Permochart," is formed of three sheets of acetate, laminated under pressure, with the chart design printed from precision plates on an inner, opaque sheet placed between two sheets of smooth, transparent acetate. The bond between laminations is made so close under the newly developed method of manufacture that moisture cannot penetrate, and the all-acetate construction eliminates any tendency to separate or buckle due to atmospheric changes.

Adjustable Lamp Socket.—In adapting new sizes of lamps to existing equipment, this adjustable socket made by the Goodrich Electric Co., 2900 N. Oakley Ave., Chicago, Ill. provides vertical adjustment for the proper positioning of lamps in reflectors.



It is equipped with two slotted prongs; a slotted ring, which holds a resilient spring-suspended socket, completes the assembly. By compressing the prongs the socket can be adjusted vertically to four positions so that changed light centers can be properly located in existing reflector equipment.

Insulating Compounds.—A new oil-insoluble insulating compound, known as "Minerallac 33," for use in cable joints, potheads, terminals, and transformer bushings has been introduced by the Minerallac Electric Co., 25 No. Peoria St., Chicago, Ill. The new compound is said to combine unusual resistivity to oil migration with high dielectric strength.

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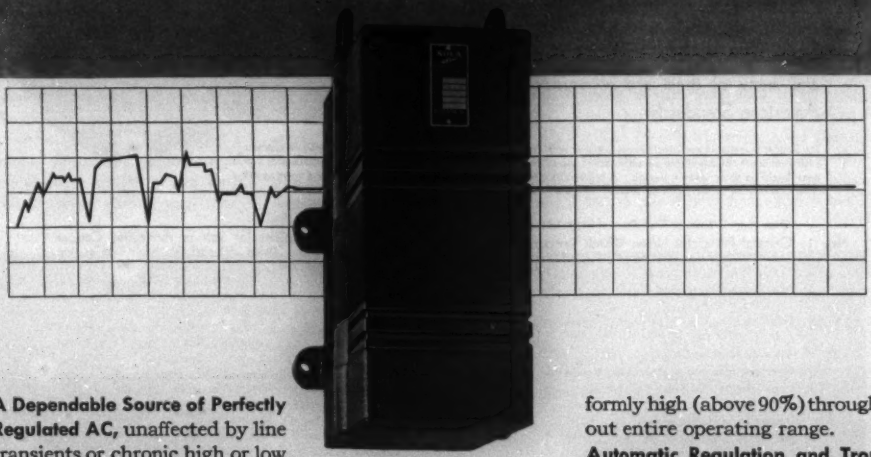

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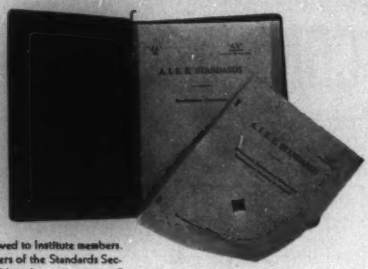

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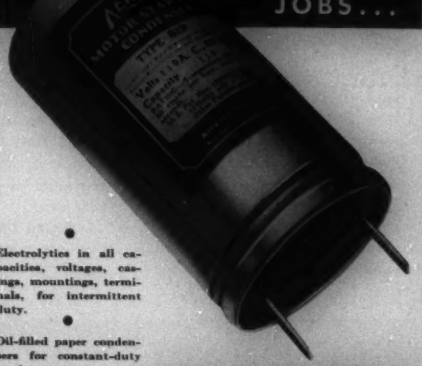

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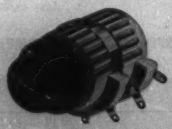

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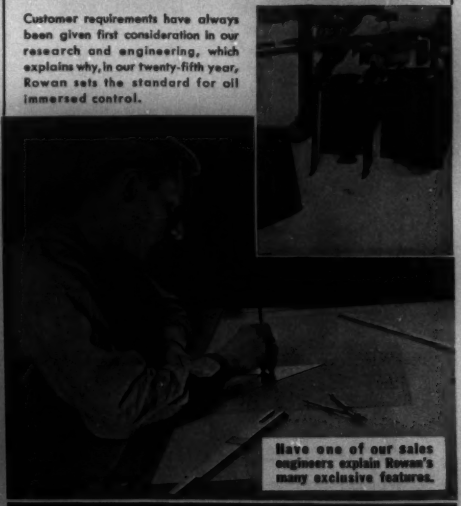

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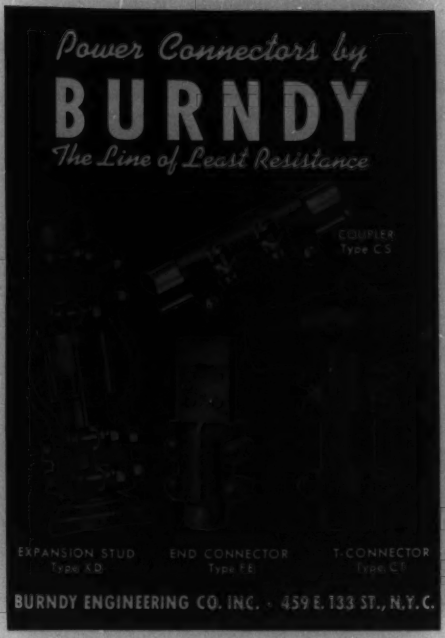

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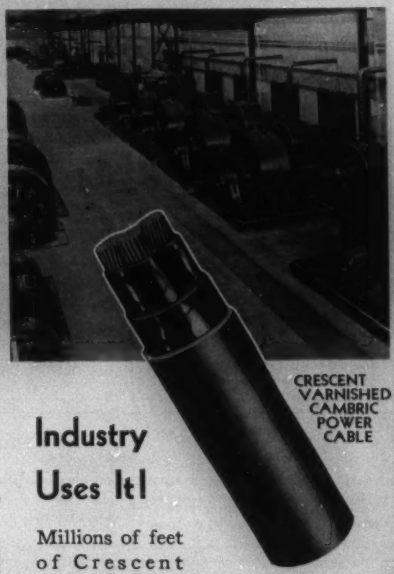

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B.E.E., '36, Minn, 23, single. Exper as sales engr, steel co maintenance engr. Bell Tel eqpt engr. Desires pos in tel com or elec pwr. Available immed. Location, West. E-409-391-C-5-San Francisco.

B.S.E.E., Duke Univ, '38; 25, single; 2 yrs com lab asst, one yr radio research. Exper radio operator, radiotel, First Class, license. Desires pos com engg. Location immaterial. Salary secondary. E-412.

B.S.E.E., 1937, Penn State, 25, single; one yr apprenticeship with Penn R.R. Desires work as jr engr with advancement. Location immaterial. Available immed. E-415.

B.S.E.E., 1935; M.S. 1937, Case; 27, single; 2 yrs grad asst mech dept; Sigma Xi, Theta Tau; exper induction hardening and control. Desires teaching, control field. E-405.

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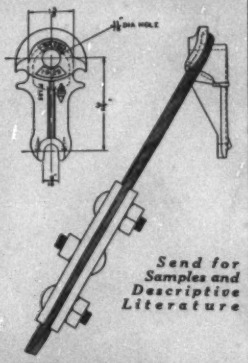

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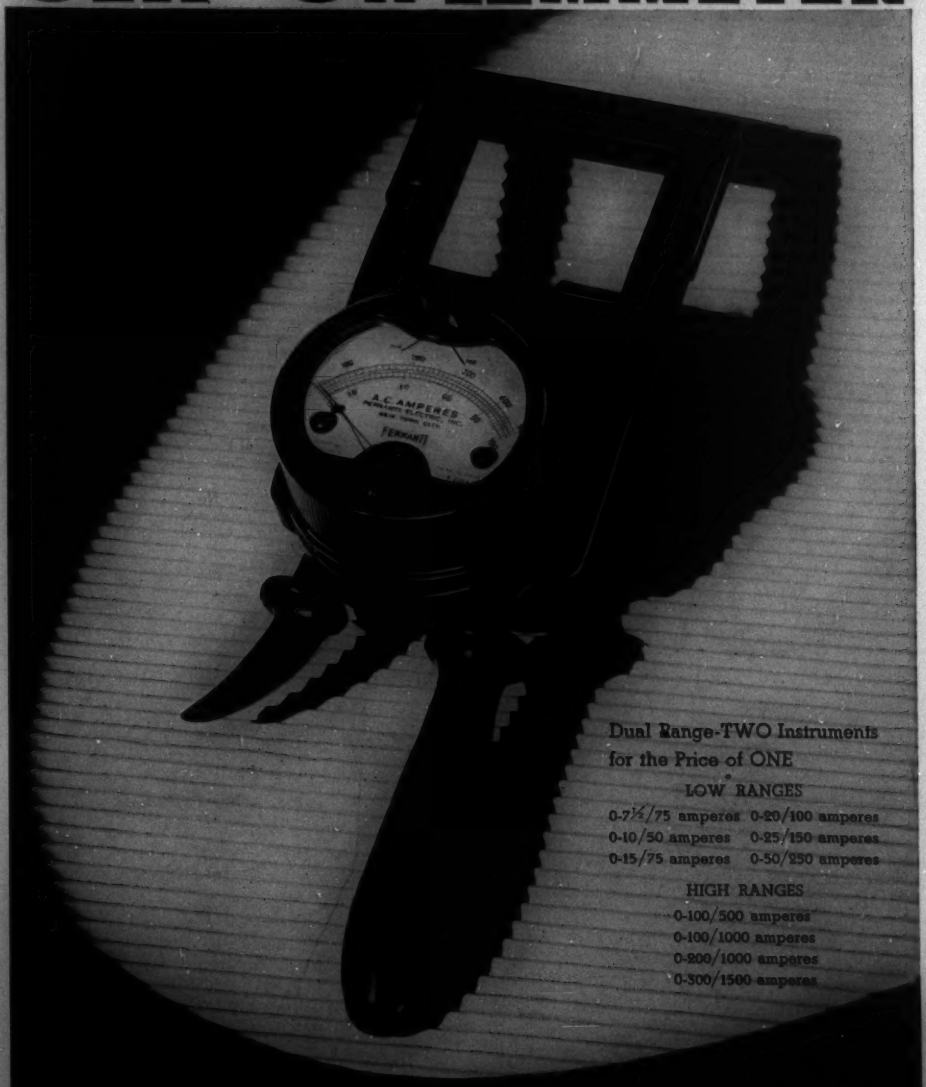

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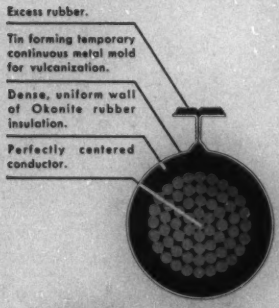
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